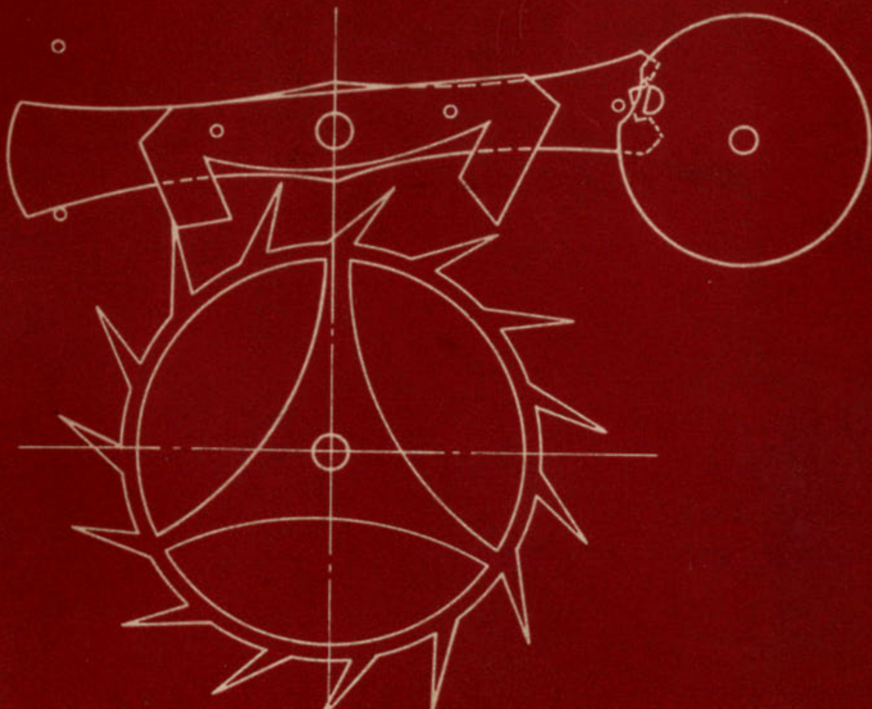
TIME MEASUREMENT

Catalogue of the collection

Science Museum



Time Measurement

Catalogue of the Science Museum Collection HMSO

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Cover illustration:
Diagram of English Lever Escapement

Science Museum

Descriptive Catalogue
of the
Collection Illustrating

Time Measurement

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Preface

The formation of a Museum of Science was first proposed by the Prince Consort after the Great Exhibition in 1851, and in 1857 collections illustrating foods, animal products, examples of structures and building materials, and educational apparatus were brought together and placed on exhibition in South Kensington. The collections of scientific instruments and apparatus were first formed in 1874, but it was only after 1876 that they became of importance. The Special Loan Collection of Scientific Apparatus which was exhibited in that year in the Museum brought together examples of all kinds from various countries, and a large number of these were acquired for the Museum. Subsequently many additions were made, including in 1884 the collection of machinery formed by the Commissioners of Patents, in 1900 the Maudslay Collection of machine tools and marine engine models, and in 1903 the Bennet Woodcroft Collection of engine models and portraits.

Until 1899 the Art Collections and the Science and Engineering Collections together formed the South Kensington Museum, but in that year the name was changed to the Victoria and Albert Museum, which included both Collections until 1909, when it was restricted to the Art Collections; those relating to Science and Technical Industry have since then formed the Science Museum.

The aim of the Science Museum, with its Collections and Science Library, is to aid in the study of scientific and technical development, and to illustrate the applications of physical science to technical industry. This is effected by the informative display of objects, diagrams and photographs—so arranged as to illustrate in each Section the development which has taken place from past to modern practice.

Many of the exhibits in the Time Measurement Section are shown in continuous operation, while others are so arranged that they can be operated by visitors or demonstrated to them. The modes of action of several of the more delicate watch mechanisms are illustrated by large-scale models.

Introduction

This Catalogue contains detailed descriptions of the objects exhibited in the Time Measurement Section of the Science Museum. These descriptions contain the substance of the descriptive labels exhibited with the various objects, but are not necessarily identical with the labels. Additional information concerning certain exhibits may be obtained by consulting the detailed references to books, journals or patent specifications given at the end of the appropriate descriptive texts. Many of these works may be seen in the reading room of the Science Library, the British Museum, or the Patent Office Library, whilst the works in the Science Library may be obtained on loan through the medium of an approved institution or industrial organisation.

The Collection is classified into a number of large groups which are further divided into sub-groups: within each sub-group the exhibits are arranged as far as possible in chronological order. A number of objects in the Collection have been photographed, and in these cases the identification number of the negative or negatives is also given, together with other information, in the index on pp. 128-143 of this Catalogue.

Prints and lantern slides from these negatives may be purchased from the Museum; in addition, lantern slides may be borrowed from the Loan Collection. For particulars of the conditions of loan and for the price of prints, etc., application should be made at the bookstall near the main entrance of the Museum, or by letter addressed 'The Director and Secretary, the Science Museum, South Kensington, London, S.W.7.' The numbered Catalogue entries include all objects on exhibition at the time of going to press. Owing to shortage of exhibition space not all the exhibits in the Collection can be shown, and the supplementary list at the end of this Catalogue contains titles and in some cases brief descriptions of the more important objects at present in store. Most of these may be seen on written application to the address given above, provided that sufficient notice is given.

1 Primitive and other non-mechanical devices

The earliest time-measuring devices which have survived to the present day are the primitive sundials or shadow-clocks and the water-clocks of ancient Egypt. These types of instrument were developed and improved by the Greeks and were in use throughout the periods of the Greek and Roman Empires; together with the sand-glass they were still the only timekeepers generally employed throughout the Dark Ages and the early Middle Ages.
The Time Measurement Collection includes casts or copies of ancient Egyptian shadow-clocks and water-clocks and a reconstruction of a remarkable Chinese astronomical water-clock; also examples of other relatively primitive non-mechanical time-measuring devices.
A collection of over 70 sand-glasses was presented to the Museum in 1952 by the Right Rev. Abbot Horne of Downside Abbey; this is referred to as 'The Abbot Horne Collection'.
The evolution of the sand-glass was in three main stages.
In the earliest type the two bulbs were separately blown; a metal plate with a small orifice was placed between the two bulbs and the whole joined together with wax or plaster to form a single unit.
After about 1750 glasses blown in one piece appeared and soon became standard, the remaining opening in one bulb being sealed with a cork.
In the third type, introduced about 1800, this opening was sealed by the glass-blower, so that the sand-glass became airtight.

1 Shadow clock

A reproduction of an early Egyptian shadow-clock. The original is in the Neues Museum at Berlin; it is made of a green schist and dates from the tenth to the eighth century BC. The instrument appears to be incomplete and requires a cross-piece as shown in the adjacent sketch.
In use the instrument would be placed with the base in an east-and-west direction, and the shadow of the edge of the cross-piece would fall upon the base, upon which a scale of 'hours' is marked. The period from sunrise to noon would thus be divided into six roughly equal parts; at noon the instrument would be reversed, and the period from noon until sunset would be roughly divided into six parts again. The 'hour' marks give the names of the hours of the day from the 'hour of rising' at the far end to the hour of 'high standing' (noon) at the vertical face.
[See *Die Geschichte der Zeitmessung und der Uhren*, edited by E. von Bassermann-Jordan, Band I, Lieferung B, *'Altägyptische Zeitmessung'*, by Dr. L. Borchardt.]

2 An Egyptian shadow-clock in use

A modern artist's impression of an ancient Egyptian taking a reading of the time as shown by a shadow-clock similar to that exhibited here.

3 'Merkhet,' an ancient Egyptian instrument for determining time

(*See Plate 1a*)

This holder for a plumb-line, called 'Merkhet' by the Egyptians, and 'horologos' by the Greeks, was used from very early historical times in Egypt to lay out axes of buildings and for observing the transit of selected stars across the meridian to determine the hour of the night. [See exhibit in the Astronomy Section.]
This example dates from about 600 BC and was the property of one Bes, the son of Khensartais, as the inscription states; he was an astronomer priest of the God Horus of Edfu in Upper Egypt.
It is of bronze, inlaid with a gold-silver alloy, electrum.

4 The Merkhet in use

A modern artists' impression of the way in which the ancient Egyptians used their Merkhets to observe the transits of certain stars across the meridian, and so to find the time of night.

5 Shadow clock

(*See Plate 1b*)

An example from Qus of a type of primitive time-measuring instrument which is still used in Upper Egypt. It is similar in principle to the ancient Egyptian shadow-clock of the tenth to eight century BC.
Mounted on the middle of a wooden board, which is placed in an east and west direction, there are two short vertical sticks which are jointed at the top by a transverse horizontal piece and resemble a miniature goal. The position of the shadow cast by the transverse piece is utilized to indicate the passage of intervals of time, the board being graduated for this purpose in the example shown by tin tacks.
Various modifications of the instrument are employed; in some a piece of twine replaces the horizontal piece, and a slab of clay is used instead of the wooden board. The 'goal posts' may also be mounted directly on a levelled surface of ground.

6 Cast of early Egyptian water-clock

The original of this cast was found at Karnak Temple, Upper Egypt, in 1904 and dates from the reign of King Amenhotep III, 1415-1380 BC; it is now in Cairo Museum. It is made of alabaster, and was probably used for indicating the passage of the hours of the night.
In use the vessel was filled with water, which leaked out slowly from a small hole near the bottom, and the time was indicated by the level of the water within. With a vessel of this shape the water-level falls fairly

uniformly, for the more rapid flow when nearly full is compensated by the greater cross-section of the vessel near its top, a greater outflow of water then being required to produce a given decrease of level.

At this epoch it was customary to divide the periods of daylight and of darkness each into 12 'temporal' hours, so that the length of an hour of the day differed from that of an hour of the night (except at the equinoxes) and both varied according to the season of the year. A separate scale of time was therefore required for each month of the year, and there are accordingly 12 series of dots marked on the inner surface of the vessel, the name of the month to which each scale refers being marked on the rim of the vessel above the scale in question.

[See *Die Geschichte der Zeitmessung und der Uhren*, edited by E. von Bassermann-Jordan, Band I, Leiferung B, *'Altägyptische Zeitmessung'*, by Dr. L. Borchardt.]

7 Photographs of early Egyptian water-clock from Karnak temple

These show the original water-clock of which a cast is exhibited adjacently.

8 Water-clock in operation

Alabaster bowls of this shape were used in ancient Egypt for measuring time during the night: a plaster cast of one can be seen in this showcase.

The water-level falls at an almost uniform rate, since the more rapid outflow when the vessel is nearly full is compensated by the greater area of cross-section of the vessel near the top.

This glass bowl shows the time in modern hours, but a different hour-reckoning system was used in Egypt, so that the hour-scales on the inside of the vessel were different.

9 'Sinking bowl' water-clock (copy)

The original bronze bowl of which this is a copy was found in a bog in County Antrim, Northern Ireland. It is of the type which was employed by the Ancient Britons, probably under the influence of the Druids, for measuring intervals of time.

The bowl has a small hole in the bottom, and in use it was placed on the surface of water, which slowly leaked into it until, after a definite interval of time, the bowl sank. The interval was used as a unit of time; in the case of the present bowl it is approximately one hour.

[See *Proceedings of the Society of Antiquaries*, vol. 21, p. 319 (1907) and vol. 27, p. 76 (1916).]

10 Algerian water-clock

A primitive form of water-clock consisting of a floating bowl, into which the water leaks through a small hole at the bottom and causes the bowl to sink after a certain interval of time, in this case about 15 minutes.

Appliances of this type are used in Algeria for timing the periods for which the various landowners are entitled to the supply of water for irrigation purposes.

11 The Chinese water-balance escapement

(*See Plate 2*)

The model represents, one-sixth full-scale, an escapement mechanism of wholly Chinese type which was fitted to an astronomical clock built in China in AD 1088 and fully described in print in AD 1172, with illustrations. The book was translated and interpreted by Drs. Needham, Wang Ling and Derek Price in 1960, and the present working model is a copy of one first made by Mr. J. H. Combridge in 1962.

Water from a constant-level reservoir flows into one of the buckets of the wheel until, at a certain point, the bucket tips a little until its lip rests on one end of the 'balance' lever. As the bucket fills still more, the balance is suddenly tipped and its lip now engages with a second lever to which the long vertical chain is attached. This slowly pulls down the right half of the long horizontal lever above the wheel until the short chain at its left-hand end suddenly tightens and pulls up the arm resting against a spoke of the wheel. The wheel is thus released and turns through the space between two spokes, when it becomes locked again and the cycle of operations is ready to begin again.

Each cycle of operations occupies 24 seconds, and as the wheel has 36 spokes and buckets it makes one complete rotation every 14 minutes 24 seconds and 100 revolutions in 24 hours.

For a given setting of the levers and weights the time of each cycle of operations depends only on the rate of flow of water into the buckets, and this can be governed very closely.

The Chinese water-balance escapement is thus a 'missing link' between the earlier water-clocks whose timekeeping depended on measuring a water level and the all-mechanical escapement clock developed in Europe about the end of the thirteenth century.

[See *Heavenly Clockwork* by J. Needham, Wang Ling and Derek J. Price (1960); also J. H. Combridge, Horological Journal, vol. 104, p. 82 (1962).]

12 Su Sung's astronomical clock-tower of 1088

The model shows the main features of the water-powered Chinese astronomical clock-tower built on the initiative of Su Sung in 1088 and described in print, with illustrations, in 1172.

The timekeeping of the clock is controlled by the water-balance escapement (shown by a model on the other side of this showcase).

The model is to a scale of 1 : 48, and the original clock-tower was 37 feet high overall.

The clock mechanism drove the armillary sphere mounted on top of the tower; and inside the tower was a celestial globe which was also rotated once in a sidereal day by the clock. The time of day was shown by 'jacks' appearing in apertures in the sides of the tower and was also sounded audibly.

The present model is a copy of one made by Mr. J. H. Combridge in 1962.

[See *Heavenly Clockwork* by J. Needham, Wang Ling and Derek J. Price (1960); also J. H. Combridge, Horological Journal, vol. 104, p. 82 (1962).]

13 Su Sung's clock-tower

The photographs are copies of illustrations in Su Sung's 'Hsin I Hsiang Fa Yao' (New Design for a Mechanised Armillary Sphere and Celestial Globe) written in AD 1092 and printed in 1172.

(1) A view of the complete tower, with the armillary sphere mounted on its roof, under an awning.

The time-indicating 'jacks' can be seen in front, and the celestial globe and the water-tanks maintaining a constant level can be seen through apertures.

(2) A more detailed view of the armillary sphere, supported by its four dragons, and with a tortoise below emitting clouds of vapour.

(3) A view of one of the internal wheels carrying the effigies of the 'jacks'.

(4) The appearance of the 'jacks' as seen through apertures in the side of the tower.

14 Details of the Chinese astronomical clock

The photographs are copies of illustrations in Su Sung's book 'New Design for a Mechanised Armillary Sphere and Celestial Globe' written (in Chinese) in AD 1092 and printed, also in Chinese, in 1172.

(1) An 'exploded' view of various parts of the clock's mechanisms. The armillary sphere, constant-level tanks, the water-wheel itself, and parts of the drive from the wheel to the sphere can be seen.

(2) A 'close-up' of the water-tanks. The feed from the upper tank maintains a constant level in the lower one.

(3) The water-wheel itself, with its 36 buckets, and the sump below to collect the water falling from the buckets.

(4) The two water-balance levers can be seen at bottom right; also the chain connecting them with the release lever above; the bare outline of the main frame; and the sump.

(5) Two 'norias', i.e. water-wheels for pumping water upwards.

15 A Chinese scene

A copy of a silhouette in low relief in the Victoria and Albert Museum.

An interesting link with the Chinese water-clock is the fact that Su Sung describes the release chain of the water-balance escapement as 'the crane-bird's knee'.

16 A medieval monastic water-clock

The painting is an enlarged copy of an illustration of a water-clock in a manuscript in the Bodleian Library, Oxford, which dates from about AD 1285. There can be no doubt that the object depicted is a timekeeper, for the narrative beside the illustration in the original document is a description in Latin of the Biblical Miracle of King Hezekiah and the backward movement of the sun as shown by a dial.

The illustration does not show clearly how the water-clock operated, but the clock evidently bears some resemblance to the Chinese water-clock a model of which is exhibited nearby.

[See *'Antiquarian Horology'*, volume 1, p. 54 (1954).]

17 Water-clock

This form of water-clock or clepsydra indicates hours of equal lengths and was introduced about the middle of the seventeenth century. The example is of English make and of about 1700.

It consists of a closed metal cylinder or drum suspended from a stand by means of two cords attached to a horizontal axle, which projects from the flat ends of the drum. The drum contains a small quantity of water and a number of partitions passing from its circumference tangentially to an imaginary circle of about one-third the diameter of the drum. When the drum is wound up, the cords are wrapped round and round the axle and the water falls over the inner and open edges of the partitions into the lowest portion of the drum. The weight of the drum then tends to make it descend, while the weight of the water in the bottom part opposes this motion which would, in the first place, involve raising this water to a higher level. As, however, the partitions are perforated, water can pass gradually from one chamber to another, and the drum descends slowly, the position of the axle indicating the time on a vertical scale.

18 Water-clock

A modern version of a drum water-clock similar in principle to the seventeenth-century example shown on the left. The drum itself has a perspex back, so that the water inside can be seen.

19 Lamp timekeeper

An eighteenth-century oil clock from North Germany. It consists of a pewter stand and lamp, the reservoir of which is of glass and graduated from 8 p.m. to 7 a.m. to indicate the hours of the night by the quantity of unburnt oil left in the reservoir.

No approach to accuracy could have been obtained with this lamp, which has an egg-shaped reservoir and an equally divided scale over its full length. Some lamps of this type, however, have reservoirs which are cylindrical except for the ends.

20 'Atmospheric' timepiece

In this nineteenth-century timepiece a pellet of mercury falls slowly down a uniform glass tube each end of which contains a porous plug. The rate of fall of the pellet is governed by the viscous flow of the air through the two plugs. The whole is sealed within an outer glass tube, and the time is shown by the position of the pellet relative to one of two wooden scales.

The pellet falls through the full length of the tube between the plugs in 20 hours and the tubes can then be inverted.

21 The earliest illustration of a sand-glass

The oil painting shown here is a copy of part of a large fresco of 1337-9 depicting Good Government by Ambrogio Lorenzetti in the Palazzo

Pubblico in Siena, Italy. The figure of Temperance holds in her right hand a large sand-glass of the typical early form with two separate bulbs bound together at the necks.

22 An early illustration of a sand-glass

This oil painting is a copy of an original painting of 1442 of St. Jerome, almost certainly by Jan van Eyck, now in the Detroit Institute of Fine Arts, USA. It shows an astrolabe hanging on the wall and, resting on the table, a typical wood-framed sand-glass.

23 A sand-glass in use

The illustration of a medieval stamping mill is from 'Das Feuerwerkpuch' a treatise on the manufacture of fireworks written in Western Germany, about 1450.

An operation is being timed by the sand-glass shown on the left.

24 A six-stage sand-glass

This probably dates from the early seventeenth century and is of the earlier type in which the main bulb and the six-stage bulb are blown separately and then pressed together at the necks.

The half-hour period of the glass is sub-divided by the six smaller bulbs, each of which empties or fills in five minutes.

Inversion of the glass was made simple by fitting it to a wall pivot by means of the hole in the back of the wooden case.

When acquired, the necks of the two bulbs were without binding and badly damaged, and permitted the obvious loss of sand. The original diaphragm is missing and has, at some time, been replaced by a small glass tube very crudely inserted in the main bulb. The present joint of putty was added in the Museum.

25 Set of four sand-glasses

Dates probably from the seventeenth century. The glasses are mounted in a brass frame pivoted to a fitting which can be hung on a wall, so that they can be inverted as required. The glasses measure intervals of time of quarter, half, three-quarters and one hour respectively, and are of the type which was formerly used by preachers for timing their sermons.

26 Set of four sand-glasses

This set resembles the adjacent one, but is mounted in a wooden frame. There is no pivoting arrangement in this case, and the frame is intended to stand either side up upon a flat table.

27 Sand-glass

A sand-glass with cylindrical bulbs, graduated up to 19 minutes.

Although the action of a sand-glass has some resemblance to that of a water-clock there is a fundamental difference in that the rate of passage

of the sand is independent of the height of the column above the orifice. The angle of the double cone connecting the two chambers at the orifice is made equal to the angle of repose of the sand.

28 Set of four sand-glasses

This set of glasses in an ornate mount of ebony and ivory is probably Italian and two of the glasses bear the date 1720.

The glasses are marked 1/4, 2/4, 3/4 and 4/4 respectively; the time intervals are also indicated by the appropriate number of ivory studs set above and below each glass on the enclosing panels, each stud representing a quarter of an hour.

The filling is of fine emery powder instead of sand, the construction being that of the early type in which two separate bulbs are joined at the necks.

29 Four-hour sand-glass

It has long been customary in ships to divide up the 24-hour day-and-night period into intervals of four hours, termed 'watches', half the ship's company being on duty during each watch. This large sand-glass, which probably dates from the eighteenth century, is of the type which was used in ships for marking the lengths of the watches. The glass would be hung up by its ropes and inverted at the end of each watch.

The four-hour period from 4 p.m. to 8 p.m. was divided into two watches, each of two hours' duration, and the passage of every half-hour was signified by an appropriate number of strokes on the ship's bell. An additional 30-minute sand-glass was supplied for timing these shorter intervals.

30 Portable sand-glass in brass case

This probably dates from the seventeenth century and is of the earlier type in which two separate bulbs are joined together at the necks.

31 Sand-glass

A nineteenth-century example, of the type used in ships in connection with the hand log for obtaining the speed of the vessel. Its sand passes from the upper to the lower chamber in a period of 14 seconds, and the instrument is inverted when it is again to be used.

From the Abbot Horne Collection

32

Single sand-glass dismantled, showing two bulbs and one diaphragm.

33

Pocket sand-glass in a double leather case which is closed by twisting. Fine emery powder is used instead of sand. Fifteen minutes.

34
Tea-taster's sand-glass, used for timing the infusion of tea. Each of the four small bulbs fills or empties in one minute.

35
A typical example of a half-hour glass in an ebony mount with turned columns and ivory feet.

36
Early portable sand-glass in a double brass case. Running time $12\frac{1}{2}$ minutes.

37
Divine office glass in a double brass case. Running time $9\frac{1}{4}$ minutes.

38
Early quarter and half-hour double glass. The joints are wax or plaster bound with leather.

39
One-hour sermon glass in a plain wooden mount. Beneath the base of each bulb are Latin inscriptions around, at one end, the coloured picture of a chalice and at the other, the initials 'J.H.S.'

40
Single sand-glass unmounted, showing corked entry hole.

41
Portable sand-glass in silver mount, hall-marked 1799. Fine emery is used instead of sand. Running time four minutes.

42
Fourteen-second log-glass in a crude wooden mount. Used in conjunction with a hand-log to estimate a ship's speed.

43
Fourteen-second log-glass in a brass case. The filling is of fine emery powder.

44
An hour-glass in a wooden mount with turned columns.

45
Half-hour glass. It has a ground waist with a copper diaphragm and is sealed with a cloth-covered cork.

46
Single sand-glass unmounted, showing complete seal.

47
Alarm sand-glass. The glass is mounted in a wire framework in such a manner that, at a preset time up to $4\frac{1}{2}$ minutes, it causes the bell to be struck.

48
'Egg Timer,' mounted in a swivel iron frame on a brass base. $2\frac{1}{2}$ minutes

49
Half- and one-hour double glass. The half-hour glass is probably a replacement.

50
Early quarter-minute pulse glass used by doctors and nurses when taking a patient's pulse rate.

51
Modern (1948) quarter-minute pulse glass.

52
Half-hour glass in polished wooden mount.

2 Sundials

Fixed sundials indicate the time by means of the sun's position or 'hour-angle' in the heavens; they are designed for use in the latitude in which they are set up, and would not show accurate time if set up in any other latitude.
Portable sundials can be divided into two main classes:
(1) Compass dials, which embody or require a compass for setting in the correct position and depend, like fixed dials, upon the sun's position in the heavens.
(2) Altitude dials, depending upon the sun's height or 'altitude' above the horizon.
Compass dials almost invariably employ a gnomon set parallel to the earth's axis, since with this construction the same scale of hours serves for all seasons of the year. All altitude dials embody a scale of dates, since the time cannot be found from the sun's altitude alone unless the date is known.
Portable dials of both classes may be designed for use in one latitude only, or may be 'universal', i.e., adjustable for use in any latitude within a wide range.
Some portable sundials are small enough to be carried in the pocket, and these pocket dials are separately grouped in the Museum Collection.

53 Plaster cast of a Roman sundial

The original dial from which this cast was made is in the British Museum, and was found at Civita Lavinia, near Rome. It is of limestone, and is of the type known as the 'hemicycle', said to have been invented by Berosus, the Chaldean astronomer, about 300 BC.
In Greek and Roman times the function of the sundial was to divide the period from sunrise to sunset into 12 equal parts, and this the hemicycle does. The gnomon, now missing, consisted of a style projecting horizontally from the centre of the curved uppermost edge of the dial. The shadow of the tip of this style would describe each day a curve on the hollowed-out portion of the dial, crossing in succession the 11 engraved hour-lines. At the summer solstice, the shadow would follow the lowermost curve, at the winter solstice the uppermost curve, and at the equinoxes the intermediate curve.
Measurements show that the dial is designed fairly accurately to indicate time on the Roman system at the latitude of Rome, 42°N.

54 Early English sundial

A plaster cast of the stone sundial in the south face of Bewcastle Cross,

Cumberland, prepared from a similar cast in the Royal Scottish Museum, Edinburgh. The dial markings are cut on the actual stone of the cross, which also bears various inscriptions. One of these can be transcribed as 'First year of the king of this realm Ecgfrith' and this inscription enables the cross to be dated at approximately AD 670.
At this period it was customary in England to divide the day from sunrise to sunset into four 'tides', and corresponding to this division the dial possesses four main hour-lines—a horizontal one for sunrise and sunset, a vertical line for midday and two intermediate lines, which are drawn at 45°. Each of these main lines is marked with a cross-stroke, and there are in addition two intermediate lines between each pair of the main lines. These correspond to a division of the day into 12 parts, but it is possible that they were cut at a later date.
The gnomon is missing, but it is conjectured that it stood out horizontally. Such a gnomon would divide the daylight hours into only approximately equal parts and dials of this type would thus give only a rough sub-division of the day.

55 Cast of a Saxon sundial

A cast taken from the stone sundial over the south porch of Kirkdale Church, near Helmsley, Yorks. From the inscriptions surrounding it, which are described in detail near by, it can be dated with confidence between AD 1055 and 1064.
It is intended to divide the daylight period, from dawn to dusk, into four equal periods or 'tides' according to the Saxon custom, and for this it required a horizontal gnomon, which is now missing. The extra line during the first 'tide', marked with a cross, was presumably intended to mark the time of a religious service or office.

56 Garden sundial

(*See Plate 3a*)

A typical horizontal sundial for use in gardens, made by William Deane, London, in 1718.
It has an ornamental gnomon for a latitude of $51\frac{1}{2}$° (that of London) and is divided to read minutes.
Inside the hour circle there is a graduated circle of dates with a ring of figures giving the 'equation of time' for each date—the difference between mean or 'clock time' and sun time.

57 Types of fixed sundials

The commonest form of fixed sundial is the horizontal type shown top left in which the dial is a horizontal plate on top of the stone column.
Next after this is the vertical south dial shown top right.
The centre illustration shows a south wall, but the sundials mounted on it face SE and SW respectively: these are termed 'declining' dials.
At bottom left we see an equatorial sundial in which the dial is a semicircular ring parallel to the earth's equator with the hour-marks on its inside, the shadow being cast by the centre rod which is a polar axis.
At bottom right we see dials of several forms mounted on a column.

58 Horizontal sundial

This eighteenth-century dial, made by Franz Antoni Knitl of Linz, has a string gnomon and the time is indicated by a pointer, which is turned until the shadow of the string falls along a radial line on the pointer. The gnomon is set for a latitude of 48° and the pointer indicates the time to one minute. A magnetic compass is provided for setting.

59 Horizontal sundial

This instrument, of French make, is dated 1782, and its gnomon is fixed on a small cannon, which may be discharged at noon.
A lens carried on an adjustable arm projected an image of the sun on the touch-hole of the piece.

Cubical Sundials

60 Cubical sundial

(*See Plate 3b*)
A Florentine instrument made about 1560; it is of wood painted in distemper with arabesques. The cube has dials with short styles on five of its faces.
The dials on the north and south faces indicate the time in old Italian hours, in which system the day was divided into 24 equal hours beginning and ending at sunset, while the top dial shows Babylonian hours in which the day similarly consisted of 24 hours beginning at sunrise.
The east and west dials indicate the time in the ancient Jewish system in which the periods from sunrise to sunset and sunset to sunrise were each divided into 12 hours the length of which depended upon the time of year and also upon whether the hours of day or of night were being recorded.
The instrument shown is for latitude 46°. It was formerly in the Pitti Palace, Florence.

61 Cubical sundial

An eighteenth-century instrument, by D. Beringer, with five gnomons giving readings on different faces of a cube.
It is designed to be level at a latitude of 50°, but it is mounted on a jointed stand and could be set for other latitudes by means of a graduated scale and a plummet (now missing). This instrument forms an interesting illustration of the manner in which sundials can be drawn on any plane provided the edge of the gnomon is parallel to the earth's axis. A compass is provided for setting the instrument in position.

Cup Sundial

62 Italian cup sundial, 1580

The time is shown by the position of the shadow of the tip of the vertical style.

There are two sets of hour-lines in the cup: the full curved lines numbered 9 to 24 for reading the time in 'Italian' hours, and the broken lines numbered from 6 to 12 and 1 to 5 for reading in hours a.m. and p.m.
The sundial is inscribed:
HYERONIMUS VULPARIÆ FLORENTINUS FACIEBAT A.D. MDLXXX.

Portable Universal Compass Dials

63 Portable universal sundial

A sundial made by Christopher Köhler, Dresden, 1677. On the base is mounted a folding equatorial hour circle which has a pin gnomon and can be adjusted for the latitude required by means of a graduated quadrant.
The hour circle is double, an inner one showing ordinary hours being surrounded by an outer one which can be rotated and adjusted in position to show Italian hours.
The instrument can be folded flat, and the cover has lunar circles outside and a perpetual calendar on the interior.

64 Universal ring sundial

This eighteenth-century instrument, of German make, has a pin gnomon, the shadow of which, on an equatorial hour circle, indicates the time. Beneath the base is inscribed 'No. 116 Se 61812. Toda M. Adakymoe'. A compass is provided, as well as a plummet for adjusting the instrument to various latitudes. A gap in the ring allows it to be used about noon at the equinoxes, when the shadow of the front edge of the hour circle would otherwise prevent readings.

65 Universal sundial

In this late seventeenth-century German sundial an arm parallel to the equator carries the equivalent of a pair of parallel plates, the edges of which are parallel to the polar axis.
The time is indicated by the position of the shadow cast by one or other of the edges of the upper plate, upon the upper surfaces of the lower plate and upon the vertical surfaces between the two plates.
The instrument is made of copper, and the arm, which is hinged, can be adjusted for different latitudes. For convenience of construction the plates are not made continuous.

66 Universal ring sundial

An eighteenth-century sundial with an equatorial ring, which is hinged to the base plate and is so adjusted for latitude.
The time is shown by the shadow of the edge of a plate mounted in the ring. The various parts of the instrument can be folded flat.

67 Portable universal compass sundial

A dial by Dollond, the well-known eighteenth-century London maker. It consists of an ordinary horizontal dial designed for a latitude of 60°,

the whole dial with its gnomon being hinged at one end so that it can be tilted up out of the horizontal plane and so used over a wide range of latitudes from 60° down to zero. An arc graduated in degrees of latitude is provided so that the instrument can be readily set for use in any given latitude.
The instrument embodies a compass so that it can be set in the correct orientation and is provided with three levelling screws and two spirit-levels arranged at right-angles to one another, so that it may be accurately levelled. For convenience in carrying it is arranged to fold up into a small space.

Column Sundials

68 The earliest illustration of a column sundial

The adoration of the Shepherds. An enlargement from a 'Horae' printed by Pigouchet in Paris in August 1498.
The shepherd immediately to the left of the Virgin and Holy Child is carrying a column sundial, of the type commonly referred to as a 'Shepherd's Dial'.
The photograph nearby shows an actual pocket ivory column dial dated 1455 in the Germanisches National Museum, Nuremberg.

69 Column sundial

This is of gilt bronze and was made in Augsburg, Germany, about 1550. It consists of a vertical cylinder mounted upon a cubical box and the time is indicated upon the sides of the box as well as on the cylindrical surface.
On the top of the cylinder there is a horizontal gnomon mounted on a loose cap which is adjusted by rotation for the sun's position in the zodiac. The instrument is then turned until the shadow of the gnomon is vertical, and the tip of the shadow will indicate the time by reference to a series of inclined hour lines on the cylinder. As, however, the measurement depends upon the sun's altitude, which is the same at approximately equal intervals of time before noon and afternoon, it is necessary to know whether the sun is east or west of the meridian, and a magnetic compass consequently forms part of the instrument.
The time is indicated on the faces of the cubical box by the positions of the tips of the shadows of short horizontal styles.
This instrument is for a latitude of 48°, and the cap, gnomon, and styles are not the originals. Representations of men taking various observations are engraved on the sides of the box.

70 Column sundial

This seventeenth-century instrument is similar in principle to the adjacent sixteenth-century column sundial, but the column is surmounted by a figure of a dragon, the tail of which serves as the gnomon. It is designed for use in a latitude of 45°.

71 Portable wooden column sundials

The left-hand sundial dates from the second half of the seventeenth century or possibly a little later, and is designed for use in a latitude of 46°. The sundial on the right, which probably dates from about the same period, bears a map of Bavaria and is designed for a latitude of about 48°; as it was without a gnomon when received the gnomon shown was made up in the Museum.

72 Wooden column sundial

A seventeenth-century sundial bearing a painted figure of St. Christopher. A column or cylinder sundial enables the time to be found from the sun's altitude. The cap of the dial, carrying the gnomon, is rotated by hand until the gnomon is vertically above the date on which the dial is being used. The dial is then suspended by means of the cord attached to the ring on its topmost point, and turned until the gnomon faces the sun. The shadow of the gnomon then lies in a straight line down the side of the cylinder, parallel to its axis, and the time is indicated by the position of the lowest point of the line—the shadow of the tip of the gnomon.
When not in use, the gnomon can be folded up and inserted inside the body of the dial, the cap being removable.
The base of this sundial can be rotated so as to show the time in various parts of the world when it is known at some standard place.

73 Tibetan priest's time-stick

An instrument, from Darjeeling, similar in principle to a column sundial. It is provided with eight time scales, and to find the time the wire gnomon is plugged into the horizontal hole at the top of the scale corresponding to the month in question and the stick is turned until the shadow of the gnomon falls straight down the scale, the time being then shown by the lower end of this shadow.

74 Cup, chalice or goblet sundial

This sundial is dated 1596 and is designed for use in a latitude of 42° (that of Rome).
The gnomon consists of a pointed rod forming the axis of the chalice, and the shadow of its tip falls on the hour-lines which are engraved on the inside of the vessel. There are three sets of hour-lines showing respectively Italian hours (1-24, starting from sunset), equal hours, and 'planetary' or temporal hours dividing the sunrise to sunset period into 12 equal parts.
To use the dial, it is rotated until the shadow of the gnomon falls in the sector corresponding to the month in question.
The dial is provided with a small plumb-bob for levelling.

75 Horizontal and analemmatic sundial

With a combination of these two types of dials it is possible, by turning the instrument until both dials indicate the same time, to dispense with

the use of a compass for setting. It is, however, necessary to know whether the sun is east or west of the meridian as similar readings on the two dials can be obtained in two positions corresponding to equal altitudes of the sun.
The horizontal dial has a folding gnomon for a latitude of 51° and, in addition to the ordinary hour-lines, there are curves indicating the paths at different times of the year of the shadow of a notch in the edge of the gnomon.
In an analemmatic dial the hours are indicated by the intersection of the shadow of a vertical gnomon and an elliptical scale of hours. The gnomon has, however, to be adjusted in a north and south direction according to the time of the year.
A plummet and scale allows the instrument to be set for latitudes between 40° and 60°.
This sundial was made by Engelbrecht, Beraunae in Bohemia, 1784.

Portable Universal Altitude Dials

76 Universal ring sundial

An eighteenth-century instrument of French make, indicating the time by light from the sun passing through a pin hole on to a graduated ring parallel to the earth's equator.
The pin hole is in a piece which slides along an axial bar parallel to the earth's axis, and the position of the pin hole is adjusted daily to correspond with the changes in the sun's declination. The equatorial ring and the axial bar are mounted inside a ring, which is set in the meridian and which itself slides within an outer meridian ring. The latter is fixed to the base of the instrument but the inner meridian ring carries a scale of latitudes of various places and can be adjusted for any latitude.
In use the pin hole is set to the date and turned to face the sun; the whole instrument is then rotated about a vertical axis until the spot of light passing through the pin hole falls exactly upon the hour circle, where it indicates the time.

77 Portable universal ring sundial

This instrument was made by Cary about 1800 and resembles the adjacent example, in which the time is indicated by the sun's rays passing through a pin hole, the resulting spot of light falling upon a circular scale of hours. The position of the pin hole has first to be adjusted to the correct date, and the dial is then suspended from the thumb or finger and rotated about a vertical axis until the spot of light falls exactly upon the hour circle. In general, two possible positions will be found, one showing a time before noon and one an equal number of hours after noon.
In order to ascertain whether the time is before or after noon (if not already known) a second observation must be made after an interval of several minutes.
The uncertainty is due to the fact that the time is actually found from the sun's altitude in the heavens, and for the same reason the time cannot

be found accurately in the neighbourhood of noon itself, when the sun's altitude is changing only slowly.

78 Universal sundial

An equatorial dial arranged to indicate the time by pointers showing hours and minutes. It is inscribed 'Filippo et Hover. Fratelli De Bianchy No. 8, 1764'.
The dial is hinged to the base plate to allow of adjustment for latitude and bears a pointer on which a sighting system is carried. This system consists of a pin hole and a small disc mounted on a hinged arm which can be moved perpendicularly to the plane of the dial and so adjusted for the declination of the sun, a sector marked with dates being provided.
In use, the spot of light from the pin hole is made to fall on the centre of the disc. The pointer then indicates the hours on a scale on the dial. The outer edge of the dial is toothed and gears with a pinion which is mounted on the tail end of the pointer and carries a hand which moves over a scale of minutes. When adjusting the position of the spot of light this hand is moved by a small key.

79 Wheatstone's solar chronometer

In this instrument, made by Elliott, London, the time is indicated on a dial by hour and minute hands as in an ordinary watch.
Mounted on bearings on a polar axis there is a tube with a lens at the end, and when this tube is so adjusted that an image of the sun falls on the centre of a system of concentric circles the hands show the time.
Two scales with verniers are provided, one for setting the polar axis for latitude and the other for adjusting the tube for the sun's declination. The dial is fixed on the polar axis, while the hands are connected by gearing with the tube. A spirit level and three levelling screws are provided and the minute scale is divided into 10-second divisions.

Pocket Compass Dials

80 Portable sundial

A French or Italian dial made about 1600. It consists of a bronze cup containing a magnetic needle and carrying a horizontal dial on its rim.
A small folding gnomon for a latitude of 42° is mounted over the mouth of the cup.

81 Horizontal sundial

A portable eighteenth-century dial, by N. Bion, Paris, with a folding gnomon for use at a latitude of 42° and including a magnetic compass for setting.
In addition to the ordinary hour scale, there are scales for showing Babylonian and Italian hours, which are indicated by the shadow of a notch in the gnomon.

Round the margin of the dial there are the names of various places, each of which is arranged according to the time at Rome when it is noon at the place.

82 Brass pocket sundial

A simple compass sundial with folding gnomon.

83 Korean pocket compass sundial

The even hour-numerals of this sundial are in Chinese characters, the odd ones in arabic numerals.

84 Pocket ebony cup sundial

Indicates Italian hours, the time being shown by the shadow of the tip of the pointed gnomon.

85 Pocket brass disc sundial

Designed for use in a latitude of 43°; the time in Italian hours being shown by the position of the shadow of the tip of the gnomon.

86 Pocket sundial and compass

Made by Walker and Son, Dublin, in the early part of the nineteenth century. It has a folding gnomon for a latitude of $51\frac{1}{2}$° and is enclosed in a brass box.

87 Horizontal sundial

A nineteenth-century dial which automatically sets itself horizontally, with its gnomon in the meridian.
The dial and gnomon are supported, by means of an agate bearing, on a vertical needle, and attached to the under side of the dial there is a magnetized rod, the position of which can be adjusted for variation.

88 Sundial

A small modern Chinese sundial made of wood.
The gnomon is a hinged pin and is set at right angles to the plane of the dial, the inclination of which can be varied. At the summer solstice the dial plane is at its maximum inclination and is approximately in the equatorial plane. If it were kept in this plane no readings could be obtained when the sun was south of the equator, but as the sun moves southwards the inclination of the dial is decreased until it is a minimum at the winter solstice. The dial is adjusted by means of a hinged strut moving over a notched scale of seasons of the year. With this arrangement there are, of course, considerable errors in the time readings.
The instrument includes a magnetic compass and can be folded flat. It is for use at a latitude of about 35°N.

89 Japanese pocket compass sundial

The time is shown by the shadow of the tip of the short vertical style.
The hour-lines divide the period from sunrise to sunset into six equal

parts according to the usual system of hour-reckoning in use in Japan up to 1866. Half-hour intervals are also marked.
The dial is oriented by means of the compass provided.

90 Persian pocket compass sundial

The signature in the central medallion on the underside of this sundial is that of 'ABD AL A'IMMA' the younger, a celebrated Persian maker of astrolabes and similar instruments who was active between 1688 and 1720.
Half of the rim of the dial is divided into degrees, the other half, nearer the gnomon, forming the hour ring. The names of certain holy places are engraved on the upper surface of the base of the dial, the lines showing their directions from Ispahan.

Tablet Compass Dials

91 Ivory tablet sundial

(*See Plate 4*)

The shadow of the string gnomon shows hours a.m. and p.m. on the circular horizontal dial and the semi-circular central vertical dial, while the shadows of the tips of the two short pointed styles show Italian hours on their respective dials. Made by Hans Ducher, 1574.

92 Pocket ivory tablet sundial

Signed 'H.D.', probably Hans Ducher, active in Nuremberg about 1580. The string gnomon shows the time of day on both horizontal and vertical faces of the dial, and the short pointed styles on these faces show Italian and Babylonian hours respectively.

93 Brass tablet sundial

A tablet sundial signed 'V.S.' (Ulrich Schniep of Munich) and dated 158–; it is intended for use in a latitude of 48°. On the outer surface of the lid is a calendar.

94 Tablet sundial

A gilt-metal folding pocket sundial of German make and dated 1597. It is designed for use at a latitude of 50° and the shadow of a string gnomon indicates the time upon a horizontal dial which surrounds a magnetic compass.
A small vertical style on the base indicates Italian hours, and a horizontal style inside the lid shows Italian hours, Babylonian hours, and the lengths of the day and the night. Below this there is a dial which, as a vertical south dial, shows ordinary 'equal' hours and, in conjunction with a bead on the string gnomon indicates the planetary or Jewish hours, and shows the sun's place in the ecliptic.
The top outside of the lid is engraved with the points of the compass and carries a pointer, while a hole in the lid enables the inside magnetic needle to be seen for the purpose of taking a bearing.

On the bottom there are circular tables giving Julian and Gregorian epacts from the years 1597 to 1615 and also a lunar circle indicating the moon's phase and time of southing according to its age.

95 Tablet sundial

A seventeenth-century German sundial with a string gnomon, the shadow of which serves to indicate the time on a plane horizontal dial on the base and on a vertical south dial on the opened lid.
In addition, Italian hours are shown on a small metal dial with a vertical style. The instrument is made of ivory and its exterior is engraved with religious pictures.

96 Tablet sundial

An ivory pocket instrument of early seventeenth-century German make with a string gnomon which can be adjusted for six latitudes, the plane horizontal dial having six corresponding hour circles.
A small vertical style shows Italian and Babylonian hours and there are two horizontal styles, one of which shows Jewish hours while the other indicates the length of the day.
A table of Julian and Gregorian epacts from 1611 to 1629 is inscribed on the under side of the base and a lunar table is also provided but its movable plate is missing.

97 Tablet sundial

An engraved ivory pocket sundial of German make and dated 1648. It has a string gnomon which can be adjusted for five different latitudes and five corresponding hour scales are provided on the horizontal dial. In addition there are two small vertical styles reading Italian and Babylonian hours respectively and a small horizontal style showing equal hours on a dial at the top of the opened lid. This dial also indicates the length of the day and the position of the sun in the zodiac.
On the outside of the lid there is a compass dial which, in combination with a rotating pointer and a hole in the lid through which the inside compass needle could be seen, allowed a bearing to be taken.
Formerly the instrument had a wind vane which when in use was placed in a hole in the middle of the compass dial and when not in use was stored in a recess in the side of the base.

98 Italian ivory tablet sundial

A dial showing Italian hours. The cup dial is for use in the latitude of Venice (45°), while the vertical dial on the inner surface of the lid is for use in the latitude of Rome (42°).

99 Wooden pocket sundial

A dial of the folding tablet form in which the same string constitutes the gnomon of a plane horizontal dial and a vertical south dial.
A series of holes is provided through which the string can be threaded for various latitudes.

100 Tablet azimuth sundial

A seventeenth-century ivory pocket instrument, by Carolus Bloud, Dieppe, indicating the time by the azimuth of the sun.
Underneath a compass needle there is an elliptical scale of hours which is adjusted in position for the time of year by turning a plate on the underside of the base. In use the whole instrument is turned until the shadow of the open lid falls symmetrically on the base, and the point of the needle then indicates the time, the hour scale being so arranged as to compensate for the magnetic variation.
The lid itself serves as an equatorial dial, a scale of latitudes, marked on the right edge of the lid, being used in combination with a hinged prop to set it at the proper inclination. The time is then shown by the shadow of a movable style on hour circles on the faces of the lid.
Inside the lid there are revolving plates for lunar calculations.

101 Azimuth sundial

To use this dial, by J. Ferguson, it is rotated until the shadow of the lid falls squarely on the base, and the time is then read off from the intersection of the compass needle with the hour-lines on the paper scale at the radius corresponding to the date in question.
The hour scales incised in the wood are used when the sundial is employed as a normal tablet dial, the shadow being cast by the string gnomon.

Universal Pocket Compass Dials

102 Universal pocket sundial

This is inscribed 'Juan. Cocart. me. fe. 1596' and has a pin gnomon and equatorial hour circle.
A scale along the side in conjunction with a small prop allows the circle and pin to be set for different latitudes. When folded up the whole is enclosed in a small square gilt-metal case.

103 Universal pocket sundial

A seventeenth-century instrument, by Lorenz Grasl, Augsburg, with polar pin gnomon and equatorial hour circle.

104 Universal pocket sundial

A seventeenth-century German dial with pin gnomon and equatorial hour circle.

105 Universal pocket sundial

This early eighteenth-century dial, by Johann Martin, Augsburg, is provided with a pin gnomon and an equatorial hour circle, and the latter is so connected with a small pointer moving over a scale of degrees that

by turning the pointer, the instrument can be adjusted for latitudes between 25° and 65°.
The instrument, which includes a magnetic compass, can be folded up and is enclosed in a silver case like a watch.

106 Pocket sundial

A sundial of the 'Butterfield' type, made by Baradelle, Paris, and dating from the early eighteenth century. Though not strictly 'universal' it can be used over a range of latitudes. The gnomon can be adjusted for use in any latitude between 40° and 60° and the dial plate carries four distinct scales of hours suitable for latitudes 40°, 45°, 49° and 52° respectively.
The compass is provided with a special scale reading from 0° to 20° of arc so that the magnetic declination can be accurately allowed for. On the underside of the dial is a table giving the latitudes of 27 important towns in various European countries.

107 Pocket universal compass sundial

This early nineteenth-century instrument, signed 'Bithray, Royal Exchange, London', consists of a sundial of the usual horizontal type, but the whole dial can be tilted to allow its use over a range of latitudes from the equator to 60°N. The dial is mounted on a compass for orienting it.

108 Boxwood compass sundial

Made and signed by Hieronymus Vulparia of Florence in 1592.
The shadows of the tips of the four metal styli show the time in Italian hours and the place of the sun in the Zodiac on dials facing NW, SW, SE and NE.

Pocket Altitude Dials

109 Tenth-century Saxon pocket sundial (copy)

The original dial, of which this is a copy, was found in 1939 in the soil of the Cloister Garth at Canterbury Cathedral. It was in the form of a tablet of silver, with a gold cap and chain. The gnomon consisted of a gold pin surmounted by a chased animal head with jewelled eyes and a ball in the mouth.
To use the dial, the gnomon is inserted in the hole corresponding to the month in question, the dial is suspended by the chain and turned to face the sun, the position of the shadow of the tip of the gnomon being noted. Two dots will be seen in each month column; the lowest of these corresponds to the position of the tip of the shadow at noon, the upper dot corresponding to an intermediate time roughly half-way between noon and sunrise or sunset.
It is known that the Saxons divided the daylight periods into four 'tides' of roughly equal length, and the positions of the upper dots correspond

therefore roughly with the end of the first and third tides (noon being the end of the second tide).
The instrument measures time by the sun's altitude and is similar in many ways to the later column or cylinder dials in which the hour scales are wrapped round a cylinder instead of engraved upon two plane surfaces.
When not in use the gnomon can be inserted in a hole in the bottom of the tablet.
The sides of the dial are inscribed in Latin 'PAX POSSESSORI' and 'SALUS FACTORI'; which may be freely translated 'God rest my owner', 'God bless my maker'.
This copy of the original dial has been made by kind permission of the Dean and Chapter of Canterbury Cathedral.

110 Pocket sundial and perpetual calendar

A combination of a vertical disc sundial and a perpetual calendar, made by Johan Henrich Börner, 1693.
To set the sundial for use the arm is rotated until it is opposite the correct month and the gnomon is lifted from its socket until it stands out perpendicular to the face of the dial. The instrument is then suspended from a small shackle (now broken off) and turned until the shadow of the tip of the gnomon falls upon the scale of hours, where it indicates the time. The instrument is similar in principle to a ring dial, the tip of the gnomon corresponding to the hole in the ring.
On the reverse side of the instrument is a perpetual calendar showing the times of sunrise and sunset and the length of the day and of the night for each month of the year. A weekly calendar is also included.
The instrument is designed for use in a latitude of about 54°, that of the most northerly part of Germany.

111 Brass quadrant sundial

A sixteenth-century instrument showing 'planetary' or 'Jewish' hours on the small scale, and Italian hours on the main, large scale.
Designed for use in a latitude of 42°.

112 Ivory quadrant sundial

A seventeenth-century dial designed for use in a latitude of 44° and indicating Italian hours.

113 Pocket ivory column sundial

A column dial signed D. Stephanus F.F. 1587, designed to indicate time on the old Italian system, in which the day-and-night period is divided into 24 equal parts, starting from sunset. On this system the hours 1 to 8 always occur during the night, and it will be noticed that these hour-numbers do not occur on the dial exhibited, the smallest hour-number being 9.
Two alternative gnomons are provided: a short one for use in the summer months and a long one for the winter months when the sun is

relatively low in the heavens. Either or both of these gnomons can be folded up and contained within the body of the instrument.
The sundial is designed for use in a latitude of about 43°, and the time is shown on the scale of the red lines before noon and on the scale of the black lines after noon.

114 Pocket ivory column sundial
A seventeenth-century French instrument, indicating hours a.m. and p.m.

115 Portable 'Shepherd's' column sundial
A sundial of a type which was in common use until recently in the Pyrenees. It is in principle similar to the adjacent column dial, in which the time of day is found by measuring the sun's altitude.
The dial, which is designed for a latitude of 42°, was probably made in the nineteenth century, and is of very rough construction, the time-scales being only approximately correct.
When the dial is not in use the cap carrying the gnomon can be removed, the gnomon rotated through 90° in a vertical plane, and the cap replaced with the gnomon contained entirely within the body of the dial.

116 Horizontal and analemmatic sundial
This eighteenth-century instrument, by Baradelle, Paris, is a combined horizontal and analemmatic sundial with a folding gnomon having an angle of 45° and a vertical back edge which serves as the style for the analemmatic dial. It is similar in principle to the dial in an adjacent show-case.
In order that the vertical edge may be adjusted for the time of the year, the whole horizontal dial is made to slide on the plate of the analemmatic dial. A small arc on the north side of the instrument enables the dials to be so inclined as to serve for any latitude between 42° and 55°.

117 Portable ring sundial
Inscribed 'S.P.F. 1736' and indicates the time by means of the altitude of the sun.
It consists of a brass ring 2.1 in. in diameter and 0.8 in. wide which in use is suspended vertically from a shackle on its rim and turned about a vertical axis until light from the sun passes through a pin hole in the middle of the rim on to the interior of the ring. Inscribed on the latter are a series of vertical circles corresponding to the time of the year and when the spots of light falls on the proper position, the time is given by reference to a series of inclined hour lines.
This example has two pin holes for use in summer and winter respectively, and the vertical circles are consequently further apart than if one hole only was used.
Round the outside of the ring is a table showing the sun's place in the zodiac at different times of the year. The instrument appears to have been made for latitude 51° 30'.

118 Portable ring sundial
Dated 1716 and similar in principle to the adjacent portable ring dial, except that it has one pin hole which is adjusted in position for the time of the year and thus allows the hour scale to take the form of a series of straight lines parallel to the axis of the ring.
The pin hole is made in a small ring which is mounted coaxially on the middle of the main ring, round the rim of which it can be turned. The main ring bears a scale of dates and is slotted where necessary to permit the passage of light. This instrument is for use at a latitude of about 48°.

Pocket Universal Altitude Dials

119 Portable universal ring sundial
An eighteenth-century instrument with an equatorial hour circle and a polar axis carrying a pin hole, the position of which is adjusted according to the time of the year.
When adjusted, the instrument is suspended by means of a shackle and the time is indicated when the rays passing through the pin hole fall exactly on the equatorial hour circle.
The shackle is mounted upon a piece which can be made to slide round an outer circle and is thus adjusted in position for the latitude of observation, the necessary scale being provided. The instrument can be folded flat.

120 Pocket universal ring sundial
An instrument of German origin and adjustable for use in any latitude.

121 Pocket universal ring dial
Signed 'Manuel de Ballesteros'.
Engraved with the names and latitudes of 23 Mexican and Central American towns.

122 Universal sundial
This late seventeenth-century dial, by Johan Martin, Augsburg, has a crescent-shaped gnomon, the position of which is adjustable according to the season of the year, and the time is shown when the shadow of one of the tips of the gnomon falls exactly upon the central line of one of the two arcs of equatorial circles. The dial is exactly similar in principle to the adjacent universal ring-dials, the pin hole being replaced by the tip of the gnomon and the hour ring being divided into two portions placed back to back instead of forming a complete circle.
The inclination of the dial can be adjusted for use in different latitudes and a small plumb-bob is fitted for leveling purposes. The various parts can be folded flat for carrying.
On the underside of the sundial is a simple perpetual weekly calendar.

123 The equation of time
As soon as reasonably accurate pendulum clocks came into operation during the seventeenth century it was noticed that there was a difference

during the course of the year between clock time and the solar time shown by sundials. The amount of difference was worked out in detail by the first Astronomer Royal, Flamsteed, in 1675.
It is due to two causes.
Firstly, the earth's orbit is an ellipse, not a circle, and the speed of the earth in its orbit, and therefore of the apparent motion of the sun through the stars, has an annual variation (see yellow curve).
Secondly, the earth's axis of rotation is not perpendicular to the orbit, and this introduces a variation which has two maxima and minima during the year (green curve).
The graph shows the difference between mean and solar time for each of these two influences separately, and the total effect due to both effects acting together.

Helio-Chronometers

124 Sundial showing mean time

A sundial, of a type patented by Major-General Oliver in 1892, designed to indicate mean time directly, the equation of time being automatically allowed for by the shape of the style which casts the shadow.
This style consists of a metal plate from the central part of which a figure has been cut out. The time is indicated by the point at which the shadow of the curved edge of the plate intersects the equatorial line on the hour circle, and the plate is marked with the names of the months to show which side of the shadow is to be observed.
The hour circle is engraved with divisions every five minutes, and the instrument can be adjusted for any latitude between 60°N and 60°S.
The instrument is by Negretti and Zambra.
[*See* British Patent Specification No. 1,660 of 1892.]

125 Ferguson's solar chronometer

An example of a universal sundial arranged to correct for the equation of time.
Two pointed rods parallel to the polar axis, with their points close together, throw a shadow on to a card which is mounted in a frame forming part of a cylinder of which the rods are the axis.
On the card there is a series of curved lines corresponding to the times at which the shadow of the point crosses the lines, and the latter are so shaped as to include corrections for the equation of time. The point on a line where the shadow crosses it on any day depends on the sun's declination and it is necessary to employ two cards, one for use from June 22nd to December 22nd when the sun is moving south and one for the other half of the year.
A scale is provided for use in moving the card sideways to correct for longitude and thus obtain standard instead of local time, and the inclination of the instrument can be adjusted for different latitudes by means of a sector and plummet.

126 Universal helio-chronometer

A twentieth-century equatorial sundial, by Messrs. Pilkington & Gibbs, Ltd., Preston, which is arranged to correct for the equation of time and to indicate mean time directly. It is also adjustable to give standard instead of local time.
Mounted on an equatorial disc which turns on a polar axis there is a sighting system consisting of two plates perpendicular to the disc. The disc is turned until light from the sun passes through one or other of two small holes in the first plate on to a line on the other plate and the time is then indicated on the circumference of the disc by a fixed index. To allow for the correction for the equation of time the first sighting plate can be moved sideways by means of a cam which is operated by a second disc mounted on the main disc and bearing a scale of dates.
A quadrant is provided for setting for latitude.

Nocturnals

127 Nocturnal

A wooden instrument, made about 1700, intended for use in finding the time by night from the positions of the 'pointers' of the Great Bear or of the bright star of the Little Bear.
It consists of a circular plate with a handle and carries a scale of dates marked on its outer edge. Revolving on this plate there is a smaller plate marked with a scale of hours and carrying two projecting teeth marked 'G' and 'L' respectively. Moving on the same axis as the revolving plate there is a long pointer which projects out beyond both plates.
In use, the inner revolving dial is first adjusted for the day of the year, the projection marked 'G' being set to the date if the Great Bear is to be observed and the projection 'L' if the Little Bear. The instrument is then held parallel to the plane of the equator with its centre line in the meridian, and the Pole Star is viewed through the hole in its axis. The long pointer is then turned until its edge is in line with the particular star to be observed and the time is then indicated by the reading of the edge of the long pointer upon the hour scale of the inner plate.
The back of the instrument bears scales giving the correction to be applied to obtain the latitude from the altitude of the Pole Star, the particular figure to be used being indicated by the position of the long pointer.

128 Diagram showing a nocturnal in use

Perpetual Calendars

129 Perpetual calendar

An eighteenth-century French calendar with two rotating plates which are slotted to show portions of scales below.

By adjusting the lower plate for the month, indications are given of the sun's position in the zodiac, the lengths of the day and night in hours, and the times of sunrise and sunset. The upper and smaller plate can be set so that the days of the week correspond with the dates of the month.

130 Perpetual calendar

A calendar of eighteenth-century German make showing the phases of the moon according to its age.

131 English perpetual calendar

132 German perpetual calendar

Further collections of sundials and nocturnals may be seen in the Astronomy Section of the Museum.

3 Mechanical Clocks

All methods of measuring time are based upon the utilisation of some form of regular motion, by means of which the passage of time is translated into the traversing of space.

Mechanical timekeepers make use of some form of cyclic mechanical motion which repeats itself over and over again. In the earliest mechanical clocks a pivoted beam or 'foliot' was pushed first in one direction and then in the other by means of a toothed wheel driven by a weight, the wheel escaping through the pitch of one tooth at each double swing. Much greater regularity and accuracy can be attained by the use of a natural cyclical motion such as the oscillation of a pendulum swinging under the attraction of gravity.

A pendulum clock consists of a train of wheels driven by a weight or spring, the rate of rotation of the wheels being limited by an 'escapement' which allows one tooth of a toothed wheel to escape at each swing of the pendulum, while in the act of escaping the tooth gives an impulse to the pendulum by means of some simple connecting system, the impulse being necessary to make good the pendulum's loss of energy due to air resistance. The clock mechanism effectively counts the swings of the pendulum and records their number upon the dial.

The weight-driven clocks in the Museum Collection are divided into the following main groups:

(1) Turret clocks, i.e., large public clocks for use in bell-towers or turrets.

(2) Domestic clocks.

(3) Regulators, i.e., clocks specially designed for very accurate timekeeping.

The collection also includes a clock showing sidereal time together with a two-thirds scale copy of the astronomical clock at Hampton Court Palace.

Turret Clocks

133 Fourteenth-century clock in Salisbury Cathedral (Photographs)

There is good evidence that this clock was constructed in 1386. It was originally installed in a thirteenth-century bell-tower in the Close at

Salisbury, but was removed to the Cathedral tower in the eighteenth century and continued working there until 1884.

It was re-discovered by Mr T. R. Robinson in 1928, and brought down from the tower for exhibition in 1931. The photographs exhibited were taken in 1929.

In 1956 it was dismantled and thoroughly overhauled, and a modern foliot balance fitted to it, replacing the pendulum with dead-beat escapement to which it had been converted. It is now on view, in working condition, in the North nave aisle at Salisbury Cathedral.

The clock bears a remarkable resemblance, both in general and in details, to the Wells clock which was probably constructed in 1392 and is now in the Science Museum, exhibited near by. The Salisbury clock possesses a going and a striking mechanism, while Wells chimes the quarter in addition.

[*See The Practical Watch and Clock Maker,* vol. 2, p. 445 (1929).]

134 Wells Cathedral clock

There is good evidence that this clock was made in 1392. It is the second oldest surviving clock in England, the oldest being the Salisbury Cathedral clock of 1386, still to be seen there.

The Wells clock was formerly controlled by a foliot balance, but has been fitted with a pendulum and anchor escapement at some date after about 1670. It has three trains of wheels for going, striking and quarter-chiming respectively, and the striking is of the locking-plate type, with 'warning'. It is also fitted with gearing to operate the astronomical dial shown in photographs near by.

The clock movement was in use at Wells until 1835, and came to London for exhibition in 1871.

[*See* R. P. Howgrave-Graham, *Archaeologia,* vol. 77 (1928).]

135 Two cast steel bells set up in connection with the Wells Cathedral clock

Made by Messrs. Vickers in the nineteenth century, and made of cast steel instead of the usual bell metal.

136 Dover Castle clock

This is of special interest as being one of the few turret clocks surviving which still retains the old 'foliot balance' for its time control.

This consists of a weighted bar which is pushed first in one direction and then in the reverse one by a toothed wheel driven by a weight. The balance makes a double swing in about eight seconds and allows the main wheel to rotate once per hour.

The clock probably dates from about 1600, and was removed from Dover Castle in 1872.

There are several somewhat inconclusive accounts of its history before this latter date.

[*See* R. P. Howgrave-Graham, *The Watch and Clock Maker,* vol. 4, p. 52 (1931).]

137 Astronomical clock

The dials and astronomical gearing of the clock on Hampton Court Palace, Middlesex, were made in 1540, and the dials of the clock exhibited in the Main Hall of this building are a faithful copy, on a scale of two-thirds, of those at Hampton Court.

The astronomical gearing of the actual Hampton Court clock is simple and leads to errors which must be corrected by hand every few years, but the Science Museum clock employs a rather more complicated gearing devised by James Ferguson, FRS, about 1750 which is so accurate that it will run for at least 40 years without any relative adjustment of the three dials one with another.

The innermost of the three rotating dials goes round once in a lunar day and carries a small pointer which shows the age of the moon in days against a scale reading from 1 to 29½ on the middle dial, which rotates once in a mean solar day. The phase of the moon can be seen graphically through a circular hole in the inner dial.

The middle dial carries a long sun pointer, the edge of which shows the date and the position of the sun in the zodiac against the outer rotating dial, which goes round once per sidereal day. The pointer also shows the time of day on the outermost, fixed dial which carries numbers I to XII twice over.

The clock was made by Messrs. Thwaites and Reed Ltd., and the rotating dials were painted by W. J. Gregg and Son, both of Clerkenwell, London.

Details of the astronomical clock

The lunar train has one stage of epicyclic gearing of ratios $\frac{12}{162} \times \frac{32}{70}$.

This causes the lunar dial to make one rotation relative to the solar dial in 29 days 12 hours 45 minutes. The true value is 29 days 12 hours 44 minutes, 3 seconds.

The sidereal train has a double epicyclic gearing of ratios $\frac{14}{166} \times \frac{7}{69} \times \frac{32}{100}$,

which gives a sidereal day of 23 hours, 56 minutes, 4.09 seconds, which agrees with the true value to this accuracy, i.e. to one-hundredth of a second.

138 Turret clock

There is no definite information concerning the origin of this clock, but it was probably made in the fifteenth century and considerably modified towards the end of the seventeenth century, a verge escapement with a pendulum having been substituted for the original foliot escapement.

The wheels and frames are made of wrought iron and the frames and bars are keyed together, while the wheels and pinions are keyed to their arbors. Lantern pinions are employed, and winding is effected by means

of pinions gearing with wheels on the barrel caps. The winding clicks lock against the spokes of the great wheel.
The striking train is of the locking-plate type and strikes the hours. It is operated by a pin on the great wheel which also carries a small wheel gearing with the motion work for the hands.
The pendulum makes 70.2 vibrations a minute.

139 Seventeenth century turret clock

This clock, from St. Giles' Church, Cambridge, is of special interest as an example of the use of the anchor or recoil escapement. It was made by William Clement, London, in 1671, and was at King's College, Cambridge, until 1817, when it was transferred to St. Giles' Church.
The going and striking trains of wheels are mounted side by side in an iron frame the members of which are secured together by screw nuts. A locking-plate mechanism is provided to strike the hours and the clock is fitted with a maintaining power mechanism of the bolt and shutter type to drive it during the process of winding. Alterations have probably been made in the clock since 1671, and some of the brass wheels appear to be of a later date.
The pendulum makes 47.25 vibrations a minute and is of the type formerly known as 'royal' owing it is said to its having 'dominion' over the clock.

140 Wood-framed turret clock

A typical example from Martley Church, Worcestershire, of a type of church clock found in the English Midlands. It probably dates from about 1680.
The going train, controlled by a recoil escapement, is mounted above the striking train, which is controlled by a locking-plate. The wooden barrels for both trains are wound by capstans, and the clicks lock on the wheel spokes. The driving weights are of stone.

141 Turret clock

The setting-dial of this clock movement is signed 'Vulliamy, London, 1795', and the clock was formerly in the pediment of a building in Great Scotland Yard which formed part of the headquarters of the Metropolitan Police before the present building was erected in 1894.
The timekeeping is controlled, through an anchor escapement, by a pendulum making one beat in 18/27 seconds and a maintaining power of bolt-and-shutter type is provided. The setting-dial reads both hours and minutes and its hands rotate anti-clockwise. The striking mechanism is of the rack type.

142 Modern turret timepiece with gravity escapement

A timepiece made by Gillett and Johnston, Ltd., and controlled by Grimthorpe's double three-legged gravity escapement, the escapement now generally used in weight-driven turret clocks. It was invented by

Mr. E. B. Denison (afterwards Lord Grimthorpe) about 1854 and was employed in the Westminster clock ('Big Ben') made at that time.
As in other gravity escapements, the impulses are not given to the pendulum directly by the wheel train, but by means of two gravity arms which are raised through equal amounts by the train. The impulses to the pendulum consequently remain constant even if the load on the train varies considerably as it does in turret clocks in which the outside hands are exposed to the weather.
Though similar in principle to the Bloxam gravity escapement which is fitted to one of the clocks in this Gallery, Grimthorpe's arrangement differs in the addition of a fly, which is mounted on the escape wheel axis for the purpose of preventing violent collisions between the teeth and the locking faces.
The timepiece shown has a nickel-alloy compensation pendulum beating seconds, and is automatically wound through an endless-chain arrangement by means of an electric motor. As the driving weight falls the subsidiary chain rotates a pulley which tips a mercury switch in the motor circuit.

143 The earliest known illustration of a clock

The picture exhibited is a hand-coloured photographic copy from a miniature in a manuscript of 1406 in the Bibliothèque Nationale, Paris; the manuscript itself forms part of a book *L'Horloge de Sapience* (the Clock of Wisdom), a book of morals and not a horological treatise.
The clock is obviously weight-driven, and although the dial is unfortunately somewhat defaced it can be seen that it was divided 1 to 12 twice over in Arabic numerals.
[See *Antiquarian Horology*, volume 1, p. 49 (1954).]

144 Timekeepers of the mid-fifteenth century

This is a hand-coloured photograph of a miniature in a manuscript *L'Horloge de Sapience*, MS IV, III, f° 13V° of about 1450 in the Royal Library of Belgium, showing many types of time-keeper.
From left to right may be seen: an astrolabe; a weight-driven mechanical clock; an automatic alarm or bell-chiming machine; portable sundials of four different types; and a spring-driven table-clock with fusee drive—the earliest known illustration of this important mechanism.
[See *Antiquarian Horology*, volume 3, p. 288 (1962).]

Domestic Clocks

145 An Italian monastic alarm clock

The painting is a copy of a large fresco of 1480 by Botticelli on an inner wall of the Church of Ognissante (All Saints), Florence. The fresco depicts St. Augustine in his cell, and to the right of the Saint's head can be seen a timepiece with a rotating 24-hour dial numbered 1 to 24 on the Italian system.

146 An Italian monastic alarm timepiece

This is a hand-coloured photograph of an Italian wooden tarsia panel of about 1500 in the Victoria and Albert Museum.
In the lower half of the cupboard stands a small weight-driven alarm timepiece of a typical Italian form.
Its dial, numbered 1 to 24 consecutively in Roman figures, rotates anti-clockwise past a fixed pointer, and its timekeeping is controlled by the usual foliot balance with adjustable weights.
The size of the clock can be judged by comparing it with the chalice in the upper compartment of the cupboard.

147 Sixteenth-century chamber clock

A typical example of a weight-driven Gothic chamber clock. It was constructed before the pendulum was applied to clockwork, and its timekeeping is controlled by a 'foliot' balance, which consists of a bar carrying adjustable weights which is pushed first in one direction and then in the other by a verge and crown wheel escapement.
The rate of a clock governed by this mechanism depends largely upon the magnitude of the driving weight and the amount of friction in the wheelwork, and the timekeeping is consequently poor compared with that of a clock controlled by a pendulum.
Only one hand is provided—an hour-hand. Minute-hands were not generally added to clocks until the advent of the pendulum had improved their timekeeping sufficiently to make the indications of such a hand of some value.
The clock strikes the hours, the bell-hammer delivering the blow by its own weight, and is also provided with an alarm.

148 A clockmaker's workshop of about 1570

An engraving by Ph. Galle from 'Nova Reperta' by Van der Straet (Stradanus) showing iron clocks in various stages of construction.

149 Sixteenth-century domestic clock

A typical example of the weight-driven domestic clocks of the period. It is signed, on one of the lowest bars of the frame, 'A.L.', the initials of the Swiss maker Ulrich Andreas Liechty of Winterthur, and dated 1596. The foliot balance, the 'spire' of the clock and the dial and hand are probably not original, but made in England in the seventeenth century; clocks by this maker usually had originally a wheel, not a foliot balance. Like the adjacent larger clock, this one has a single hour-hand only. It strikes the hours, and formerly had a mechanism for showing the phases of the moon.

150 English iron lantern clock

The typical English lantern or 'bird cage' clock of the seventeenth century was made mainly of brass, but this example signed by John Holloway at Lavington and dated 1611 on the bottom plate, is made wholly of iron

with the exception of the chapter ring and hand, which have probably been renewed.
The clock is thus of special interest as being a transitional type between the German iron Gothic clock of the sixteenth century and the English brass lantern clock.
The train is almost identical with that of the later Knifton lantern clock of about 1650 exhibited nearby.

151 Lantern clock

The lantern or birdcage clock was the earliest type of clock to be made in any numbers in England, and the type persisted throughout most of the seventeenth century. The present example, made about 1650 by Thomas Knifton at the Cross Keys, Lothbury, has a verge escapement and retains its wheel balance; later clocks, made after Huygens' pendulum invention of 1657, usually had their timekeeping controlled by a short pendulum, while many of the earliest clocks were converted to employ one, owing to the improvement in timekeeping thereby attained.
The present Knifton clock has a single hour-hand, and the chapter ring is divided into hours and quarters; the striking train is of the usual locking-plate type, and strikes the hours.

152 Wooden foliot timepiece

Timepieces and clocks of this type have been made in the Black Forest area of Germany since about the middle of the seventeeth century; the date '1640' inscribed on this example relates to this fact and does not necessarily indicate that the timepiece itself was made at this date.
The earlier Black Forest clocks were almost entirely hand-made in the homes of the craftsmen: later examples are factory made and mass-produced.
The timekeeping is governed by a foliot balance driven by a verge and crown-wheel; in this example one arm of the foliot is broken off and the small weights which should hang from the notches on the foliot are missing.

153 Italian copper-gilt chamber clock

This pendulum clock is signed 'Camerini, An Dni 1656'; it has going and striking trains and probably had an alarm formerly.
It employs a light pendulum, but this is probably a later addition, as there are indications that the clock formerly had a verge and foliot balance.

154 Seventeenth-century wooden clock

This domestic clock, probably made at Davos, in Switzerland, is dated 1669 and has a verge escapement of the foliot type with a balance wheel, which has no balance spring.
The framework, wheels, pinions, and arbors are made of wood, and the great wheels of the going and striking trains have wooden pivots. The

other wheels have steel pivots which are formed of wire passing through the arbors and run in brass bushes in the frames.

The escapement wheel is of wood with inclined projecting iron teeth which engage with an iron verge. Regulation would be effected by increasing or decreasing the driving weight according to whether the clock was losing or gaining.

There are two hands moving over separate dials. The lower hand moves with the great wheel arbor and rotates once an hour, its dial being divided to indicate quarter hours, while the upper hand indicates hours. Inside the upper dial there is an alarm plate with holes into one of which a peg was inserted to actuate the alarm.

The striking mechanism is of the locking plate type and there is no 'warning' arrangement.

Pendulum Clocks

155 Copy of drawings of Galileo's proposed pendulum application

This drawing was formerly attributed to Galileo Galilei himself or his son Vincenzio, but it now appears almost certain that it was made in 1659 by Viviani, Galileo's friend and biographer, and shows the incomplete pendulum clock designed by Galileo shortly before his death in 1642 and partly constructed by his son Vincenzio who died in 1649. It represents the first certainly known attempt to apply a pendulum to control the rate of a weight- or spring-driven clock.

A nineteenth-century model showing the invention completed is exhibited nearby.

[See S. A. Bedini, *Physis*, volume V, Fasc 2 p. 145 (1963).)]

156 Model of Galileo's proposed pendulum application

The drawing forming a neighbouring exhibit shows the incomplete clock made by Galileo's son Vincenzio in 1649 to his father's design.

This model, made in Florence in the nineteenth century, shows how the design can be carried out.

It represents the first certainly known attempt to apply a pendulum to control the rate of a weight- or spring-driven clock.

[See S. A. Bedini, *Physis*, volume V, Fasc 2, p. 145 (1963).]

157 Huygens' drawing of his pendulum timepiece from 'Horologium', 1658

158 Reconstruction of Huygens' pendulum timepiece as illustrated in 'Horologium', 1658

The timepiece illustrated in this small book is controlled by a pendulum and driven by a weight through an 'endless cord'. A 2 : 1 right-angled reduction gearing is introduced between verge and crutch to reduce the pendulum arc.

The main dial has an hour hand and a hand which rotates once in five minutes. The subsidiary minute hand rotates anti-clockwise once per hour.

This reconstruction was made by A. Bowerbank at Camerer Cuss and Co., London, 1956.

159 Huygens' drawing of his pendulum timepiece from 'Horologium Oscillatorium', 1673

160 Reconstruction of Huygens' pendulum timepiece as illustrated in 'Horologium Oscillatorium',

This timepiece differs from that illustrated in Huygens' earlier work *Horologium* of 1658 in that the pendulum is hung between cycloidal 'cheeks' which, as shown mathematically by Huygens, cause the pendulum bob itself to describe a cycloidal path and not an arc of a circle. Huygens also showed that in such a path the time of swing of the pendulum is independent of the size of the arc of swing—an important property for accurate timekeeping. The geared crutch of the 1658 timepiece to reduce the arc of swing is therefore abolished, being unnecessary. The hands of the main clock dial show hours and minutes in the conventional way, and seconds are shown by a dial rotating past a fixed pointer.

161 Christiaan Huygens, 1629–1695

Huygens in 1659 was the first to calculate in detail the variation of the time of swing of a pendulum with its arc of swing.

He showed that if the pendulum could be suspended by a flexible cord or strip confined between cycloidal 'cheeks' its period of swing would be the same for all arcs of swing.

From an engraving included in Huygens' *Complete Works*.

162 Christiaan Huygens

The photograph shows a relief portrait of Christiaan Huygens, sculptured in white marble. It was made from life by the French sculptor Jean Jacques Clerion in Paris in 1679, when Huygens was 50. It is now in the National Museum of the History of Science, Leiden, Holland, by whose courtesy this photograph is shown.

163 Experiments with pendulums

This apparatus operates on a cycle lasting five minutes, started by pressing the button.

It consists of three pairs of pendulums, which are pushed aside by the setting rods and then released magnetically.

The left-hand pair have small but unequal arcs of swing, and it is seen that they keep time together.

The middle pair have unequal and large arcs of swing, and as they swing the one with the larger arc is seen to lag behind the other. When both arcs of swing become small, however, this continued lag disappears.

The right-hand pair of pendulums have unequal and large arcs of swing, but they are suspended by cords which lie between cycloidal 'cheeks', as recommended by Huygens in 1659. As he showed in his calculations, the two keep time together whether their arcs of swing are large or small.

164 Zaandam clock movement

Following Huygens' application of the pendulum to clock mechanisms, pendulum clocks of various types were made in Holland.

The so-called 'Zaandam' or 'Zaanland' clocks, named from the area in which they were made, were one of the most popular, and the movement exhibited is from one of these, probably of the early eighteenth century. The verge escapement is similar to that of the earlier type of clock controlled by a foliot balance, but the foliot itself is replaced by a metal bar which engages with a fork attached to the pendulum.

The locking-plate striking gear strikes the hours on one bell, and the half-hours an equal number of strokes upon a second bell of different pitch, a system known as 'Dutch striking'.

The pendulum shown is not original.

165 Friesland timepiece

An eighteenth-century Dutch alarm timepiece, weight-driven and controlled by a light pendulum through a verge escapement. The wooden base, backboard and hood are modern replacements.

The timepiece has a single hand only, showing the hours.

166 Lantern clock

The lantern or bird-cage clock was the first type of domestic clock to be used to any considerable extent and it appears to have been introduced about the end of the sixteenth century. The movement was enclosed in a brass case surmounted by a bell, and the clock was mounted on a bracket and driven by weights.

Before the application of the pendulum about 1660 a verge escapement with a balance wheel without a balance spring was employed in clocks of this type, but after that date a verge escapement with a short pendulum, known as a 'bob' pendulum, was used, as in this example made by Edward Webb, Chewstoke, in 1688.

The framing consists of two horizontal plates connected by four corner posts, and there are vertical bars which provide bearings for the pivots of the wheel trains. The striking train is mounted separately behind the going train and not by the side of it as in a modern clock. A locking-plate striking mechanism is employed which includes a warning arrangement. There is only one hand, an hour hand, but the hour divisions of the dial are divided into four parts. The going and striking trains are driven by the same weight by means of an endless cord arrangement.

A characteristic feature of lantern clocks is the ornamentation, by brass 'frets', of the tops of the front and sides.

167 Lantern clock

This clock, made about 1700 by John Drury, London, illustrates a transitional stage between the typical brass lantern clock of the seventeenth century and the 'long-case' clock of the eighteenth century. It is fitted with the anchor escapement, introduced about 1670, which requires a much smaller arc of swing than its predecessor, the verge, and so a longer pendulum, giving better control of the timekeeping, can therefore be employed.

The lantern clock was designed for mounting on a bracket projecting from a wall, but with the introduction of the anchor escapement and long pendulum it soon gave way to the 'long-case' clock in which pendulum and weights were enclosed in a long wooden case resting upon the floor.

The clock exhibited has only one hand, although at this period minute-hands were becoming fairly common. It is fitted with the 'rack' type of striking mechanism, invented by the Rev. E. Barlow in 1676, in which the hour struck depends solely upon the position of the hour-hand.

168 Movement of early eighteenth century long-case clock

This movement made by T. Dicker, Silchester, illustrates the last stage in the transition from the 'lantern' type of clock.

The movement bears a considerable general resemblance to that of the adjacent lantern clock. It is, of course, driven by a suspended weight and is controlled by means of a long seconds pendulum through the medium of an anchor escapement. It is fitted with a locking-plate striking mechanism and possesses only a single hand, moving over a scale of hours divided into quarters.

169 Reconstruction of one of Hooke's experiments

On 16th May, 1669, Hooke demonstrated that a long pendulum with a heavy bob could be maintained in motion by a small force, such as that of a pocket watch, and that in this way a pendulum could be kept going with a very narrow arc of swing. In Hooke's demonstration the pendulum was 14 feet long, whereas in the present reconstruction of his experiment, due to Mr. M. C. Aimer, FBHI, it is 12 feet long.

170 Long-case clock

A typical English long-case clock of about 1695, by Edward Speakman, London, in marquetry case.

Controlled by a seconds pendulum through an anchor escapement, with locking-plate striking mechanism. Runs for one month at a winding.

171 Tompion long-case clock

A typical Tompion eight-day clock of about 1700 in walnut case, with later, oak base, the back plate numbered 326. The pendulum rod is of brass and the timekeeping is controlled by a recoil escapement. The locking-plate is attached to the great wheel.

The dial has a date aperture, but there is no special provision for the short months.

172 Eight-day clock movement

Made by John Harrison, at Barrow, Lincolnshire, in 1715. With the exception of the escape wheel, the wheels and pinions are of wood, as in other early clocks by Harrison, who, although the winner of the Government award of £20,000 for the invention of his chronometer, was originally trained as a carpenter.

Each wheel is built up of oak in three layers, the teeth being cut in the middle layer, which is in four segments fastened together by two outside circular layers extending to the bottoms of the teeth. The pinions and arbors are of boxwood with steel pivots passing through their entire lengths and running in brass bushes in the frame, which is of oak.

The day of the month is shown through a hole in the dial by means of a numbered disc, the rim of which carries 31 pins and is moved once a day by a pin on a wheel which is driven by a pinion on the arbor of the striking barrel.

A cranked key is employed for winding the driving weights and it is provided with a pinion which gears with wheels on the caps of the barrels. Normally, the holes in the bottom corners of the dial through which the key is passed are covered by removable spandrel ornaments. An ordinary recoil anchor escapement is used and the striking mechanism is of the locking-plate type.

Regulators

173 Regulator

Made by Benjamin Vulliamy for King George III and formerly the principal timekeeper in His Majesty's private observatory which was established at Kew in 1769. It is fitted with the 'Grasshopper' escapement invented by John Harrison, in which the escape wheel teeth do not move along the faces of the pallets. This eliminates friction and avoids the necessity of lubrication. Another anti-friction device employed is the extensive use of friction wheels for carrying the bearings of the wheel train.

In the escapement there are two pallets, of hard wood, mounted on the ends of separate arms.

This escapement has a large arc of vibration and the pendulum receives an almost continuous impulse throughout each swing.

Each pivot of the wheel train rests upon a pair of friction wheels one of which is set higher than the other according to the direction in which the pressure of the pivot acts. The friction wheels supporting the pivots of the pallet frame are, however, arranged symmetrically. The great wheel is raised from its friction wheel bearings during winding.

A sun-and-planet maintaining power mechanism is employed to keep the clock going during winding and a gridiron pendulum is employed to obtain compensation for variations of temperature.

174 Regulator clock

A regulator, made in 1832 by the well-known maker B. L. Vulliamy, the son of Benjamin Vulliamy, and a good example of the most accurate kind of clock of the period. A clock of this type is capable of keeping time to an accuracy of approximately one-tenth of a second per day under good conditions.

The escapement is Graham's dead-beat, having jewelled and long leverage pallets. The wheels and frames are of hard hammered brass, with screwed-in bushed bearings to all pivots and adjustable end bearings. The pinions are of high numbers, viz.: 20, 24 and 22 teeth respectively, and are made of highly glossed hardened steel; the wheels also are of high numbers, viz.: 240, 180, 176 and 30 teeth respectively. The object of all these refinements is, of course, to reduce to a minimum the friction in the train of wheels.

The pendulum is fitted with Graham's mercurial compensation for change of temperature, the downward expansion of the pendulum rod in heat being compensated by the greater upward expansion of the mercury. This was the most accurate temperature compensation available at the period.

The clock goes for eight days and is fitted with Harrison's maintaining power to keep it going while being wound.

175 Regulator with gravity escapement

In a gravity escapement the wheel train does not act directly on the pendulum, but is arranged to lift gravity arms which, when falling, give impulses to the pendulum. Such impulses are constant and independent of any variations which may occur in the power transmitted by the wheel train. The gravity escapement shown was invented by J. M. Bloxam about 1850, and was the immediate forerunner of Grimthorpe's gravity escapement as employed in 'Big Ben'.

There are two gravity arms which are separately pivoted on the same axis, and the escape wheel consists of an inner wheel or pinion of nine teeth for lifting the arms and an outer wheel of nine teeth for locking the arms. The arms also carry projections which engage with the pendulum.

A compensation pendulum consisting of a steel rod with a cast iron jar containing mercury is employed.

[See *Memoirs of the Royal Astronomical Society*, vol. 22, p. 103 (1854).]

176 Riefler regulator

This regulator was made by Messrs. Thomas Mercer from designs by the late E. T. Cottingham. It employs the escapement patented by Riefler of Munich in 1889, in which the pendulum itself swings freely, while impulses are imparted to it every second from the escapement through its suspension spring. The regulator is driven by a small weighted arm re-set electrically at intervals of about half a minute.

The regulator exhibited is fitted with a maintaining power due to Cottingham which keeps a driving force in operation during the fraction of a second in which the weighted arm is being thrown up.

The pendulum swings in an airtight cylinder in which the air pressure can be maintained constant, since owing to the electrical winding no access by hand is necessary.

177 Rudd's free pendulum clock

This experimental clock, constructed by its inventor, R. J. Rudd of Croydon, in 1899, was the first to embody the principle of the Free Pendulum and Slave Clock. Rudd's actual mechanisms are very delicate and difficult to keep in adjustment and have therefore been superseded, but his idea has led to the modern Shortt clock, whose accuracy over long periods exceeds that of any other mechanical timekeeper.

The best mechanical timekeeper known is a pendulum swinging freely under gravity, but in order to convert such a pendulum into a practical clock the pendulum must be sustained in motion so that its oscillations do not die down, and the swings must be counted. In ordinary clocks the sustaining and counting functions are both carried out by the escapement and clock mechanism, but the free motion of the pendulum is considerably interfered with thereby.

In the Rudd clock the two functions are carried out by a subsidiary or 'slave' clock. This clock gives an impulse every minute to the free pendulum and the rate of the slave clock is automatically regulated by the free pendulum so that the impulses always arrive at the correct moment at the middle of a swing. If an impulse from the slave arrives too early the regulator of the slave clock is set 'slow' for the ensuing minute, if too late it is set 'fast'. The slave soon settles down so that its rate is equal to that of the free pendulum, and any subsequent variations of its rate are automatically corrected.

178 Sidereal and mean time clock

Designed by Joseph Vines in 1836 and made by Walsh of Newbury. It has two dials, showing sidereal and mean solar time respectively. The two trains of wheels are connected by gearing and there is only one escapement the pendulum of which beats sidereal seconds.

The connection between the two trains consists of a wheel of 32 teeth, on the escape wheel arbor of the sidereal train, gearing with a wheel of 247 teeth which is on the same axis as another wheel with 331 teeth. The latter gears with a wheel of 43 teeth on the same axis as the seconds hand of the mean time train. The error involved with this gearing is about .0005 seconds a day.

A supplementary moving dial is arranged inside the mean time seconds dial and this moving dial is made to rotate backward at such a rate that the same hand indicates mean time seconds on the outer dial and sidereal seconds on the moving inner dial.

A special form of gravity escapement is employed and the pendulum is of the Harrison compensation form with five steel and four brass rods.

The sidereal dial carries a hand which bears a representation of the sun and indicates the mean solar hours. There is also a moon hand which indicates the phases of the moon and shows its position relative to the sun.

4 Spring-driven clocks

The invention of spring-drive, which made portable clocks and watches possible, was made about the middle of the fifteenth century, and the first watches—portable timekeepers small enough to be carried about on the person—were made in Nuremberg shortly after 1500. In early spring clocks and watches the varying spring pull was compensated either by a very rough device known as a stackfreed or by a much better device termed a fusee.

The invention of the balance-spring about 1675 gave a great improvement in timekeeping, and subsequent improvements have consisted mainly in the invention of better escapements which leave the oscillating balance as free as possible.

The spring-driven clocks in the Science Museum Collection include table and bracket clocks.

179 Sixteenth-century German alarm table time-piece

This square timepiece dates from about 1550. Apart from the fusee, the movement is wholly of iron. The balance is in the form of a dumb-bell.

The outer ring of hour-figures runs from 1 to 24, the inner ring from 1 to 12 twice over.

The alarm can be set by rotating the inner alarm disc, which is numbered from 1 to 24.

180 Drum calendar timepiece with detachable alarm

This timepiece dates from about 1600, and has a verge escapement with a balance-wheel: the balance-spring is a later addition.

It is provided with an hour-hand and a shorter hand which indicates the day of the month on a scale reading from 1 to 31. There is no special provision for the shorter months.

The separate alarm mechanism is clipped on to the top of the clock and the alarm lever is tripped by the hour-hand.

181 Seventeenth-century English table-clock

English table-clocks of this period are far from common; this example was made by David Bouquet, who was admitted to the Clockmakers' Company in 1632 and died in 1665, and is signed 'David Bouquet à Londres'.

It is a spring-driven striking clock, and has a verge escapement without balance-spring. It is fitted with a single hour-hand, and has touch-pins for finding the time by night.
The frame and wheels are of brass.

182 Astronomical table timepiece

N. Vallin, the maker of this timepiece, was one of the few English clock-makers of the Elizabethan period. The clock shows the hour of the day (on a circle of twice twelve hours), the date, the positions of the sun and moon in the zodiac, the age and phase of the moon, the difference between solar and lunar times, and the time of high tide in London. The timekeeping part of the clock movement has been partly renewed and part of it is missing, but the gearing for the dial is complete.
The hour hand rotates once in 24 hours (solar time); the date indicator, to which the sun pointer is attached, once in 365 days; and the moon pointer makes one revolution relative to the stars in 27.43 days (192 divided by 7). The correct figure is 27.32 days, so that the error in the moon's age will accumulate at the rate of about $1\frac{1}{2}$ days per year. There is no allowance for leap-year, so that the sun pointer will err by one day every four years.

183 Seventeenth-century octagonal timepiece

This timepiece, the movement of which is inscribed 'David Weber, Aug', is presumably of Augsburg make, and dates from the early seventeenth century. It is a typical example of a table-clock of the period.
The going train is driven by a mainspring through a fusee and chain, and the timekeeping is controlled by a balance-wheel without balance-spring, through a verge escapement. The clock has a single hand, showing the hours, and is fitted with an alarm which can be set by rotating the central inner dial.

184 Seventeenth-century table-clock

Dates from about the middle of the seventeenth century: its movement is inscribed 'Geo. Cri. Lucenberg er Augspurg', a maker who died in 1660.
The timekeeping is controlled by a balance-wheel without balance-spring, and a bristle regulator is fitted. Two short bristles are mounted on a pivoted arm and engage with the diametral strip of the balance; the extent of the engagement depends upon the position of the arm which carries the bristles, and so a rather crude method of regulation is achieved.
The going train of the clock is driven through a fusee with chain, while the striking train has a going-barrel. A number of wheels in both trains appear to have been renewed.
The clock is fitted with a single hour-hand and strikes the hours.

185 Seventeenth-century table-clock

A clock of later date than the adjacent ones, dating probably from the late seventeenth century.

It is provided with both alarm and striking mechanisms, and shows minutes as well as hours upon its dial. The inner, rotating ring on the dial is for setting the alarm.
The timekeeping is controlled by a balance-wheel fitted with a balance-spring, and the going train is driven by a mainspring through a fusee and chain. The alarm and striking trains are driven by separate springs mounted in going barrels.

186 The Metzker table-clock of 1564

The transparency shows one of the best of the many fine table-clocks made in the Augsburg area of Germany during the second half of the sixteenth century.
It is by Jeremias Metzker of Augsburg and its main dial shows, besides the time a.m. or p.m. in hours and minutes, the time in Italian hours, the times of sunrise and sunset and the length of the daylight period.
Other dials on the front of the clock show (bottom left) the date, on a calendar disc covering two months; the position of the sun in the zodiac; and the Dominical Letter or Letters for the year. There are still further dials on the sides and back of the clock.
The original clock is in the Kunsthistorisches Museum, Vienna.

187 Seventeenth-century table-clock

(*See Plate 5*)

Clocks of this general type were being made at Augsburg and other centres in South Germany during the late sixteenth and early seventeenth centuries. The example exhibited here bears no maker's name or date, but was made probably about 1630.
The main part of the movement is in its original condition, but the pendulum was probably added during the second half of the seventeenth century. Many of the gear trains for driving the astronomical dial pointers are missing.
The indications of the dials are as follows:
Main dial on front of clock. The two long double-ended pointers show mean solar time and lunar time, on the outermost ring of 2 x 12 hours. The phase of the moon is shown by the circular opening in the disc carrying the moon-pointers, while the moon's age can be read off from the position of the edge of the moon-pointer of the circular scale on the disc carrying the sun-pointer. The remainder of this dial is an astrolabe, and shows the position (altitude and azimuth) in the heavens of the sun, moon and a number of selected stars shown by the small pointers on the rotating fret or 'rete'.
The lower left-hand dial gives the Dominical Letter (or Letters) for the year, and also the number of the year in the major or solar cycle.
The dial on the left side of the clock, reading from 1 to 4, shows which quarter has chimed.
The dial on the right side of the clock shows which hour has last struck, on two circles reading 1 to 12 and 1 to 24 respectively.
The main dial on the back of the clock has been mutilated, but originally showed minutes, hours on the 2 x 12 system, and also Italian hours.

The two lower dials on the back of the clock show the day of the week and the position of the sun in the zodiac respectively.

188 Early pendulum clock from Holland

A 'Haagsche Klokje' made about 1675 by Johannes von Ceulen of The Hague, who made clocks for Huygens.
A single main-spring drives both the going and the striking mechanisms. The pendulum is suspended between curved 'cheeks', as recommended by Huygens, but these are too sharply curved to give correct compensation.

189 Bracket clock

This is signed 'I. Thuret à Paris', and is the work of Isaac Thuret who made clocks for Huygens while he was in Paris during the period 1665-81. Thuret was clockmaker to Louis XIV, and died in 1700.
The going and striking trains of this clock are driven from the same main-spring, and the pendulum swings between 'cheeks' which are not, however, of the correct cycloidal form calculated by Huygens which would make the period of the pendulum independent of its arc of swing. The locking-plate has been renewed.

190 An English wood-cased bracket clock

The coloured photograph shows a fine specimen of an English bracket clock of about 1690 by Joseph Knibb of London, a maker of the same high class as Tompion.
The case of the clock is of burr walnut, there is a skeleton chapter-ring, and every minute is numbered.

191 Tompion travelling clock

(*See Plate 6*)

A special piece signed 'Tho. Tompion, London', made by this great maker about 1700. It formerly had arrangements whereby it could be controlled by either a pendulum or a balance-wheel, but these have been removed and the clock is now controlled by a later lever escapement.
Parts of the alarm, striking and repeating mechanisms are missing.

192 Bracket clock

A good example of the work of George Graham, FRS, who died in 1751. It is numbered 764 and was probably made towards the end of his life. It repeats the hours and quarters, has a verge escapement, and is provided with Graham's regulator in which the pendulum suspension spring passes between a pair of jaws.
The day of the month is indicated through the small aperture low down on the dial.

5 Japanese clocks

Modern time-reckoning in equal hours was not introduced in Japan until 1870. Previously to that date, Japanese clocks were designed to indicate 'temporal' hours, i.e., to divide the periods of daylight and darkness each into six divisions. The 'hour' intervals were numbered 9, 8, 7, 6, 5, 4 respectively from midday to midnight, and in the same sequence again from midnight until midday. Japanese striking clocks were therefore designed to strike the hours according to this system; at the half-hours a single stroke was sounded and, at the alternate half-hours, two strokes. The sequence of strokes given by a Japanese striking clock was therefore, 9, 1, 8, 2, 7, 1, etc.
Japanese clocks may be divided into three main classes— 'Lantern', 'Bracket' and 'Pillar' clocks. The Museum collection includes examples of all three types together with other Japanese table clocks.

Lantern Clocks

193 Japanese 'lantern' clock

(*See Plate 9*)

This clock indicates the time on the old Japanese system in which the periods of daylight and darkness are each divided into six intervals. On this system day and night hours are of different lengths, and in this clock two separate escapements, each complete with crown-wheel, verge and foliot balance, are provided, one being in use during the daytime and the other at night. The change-over at dawn and dusk is automatically carried out by the striking mechanism.
Two crown wheels on one arbor are driven by the going train of wheels, and as the clock is striking the hour corresponding to dawn or dusk a pin in the count-wheel of the striking train engages with a pinion of six leaves and turns it through one-sixth of a revolution. On the same axis as this pinion are two triangular cams, and these cams move levers which engage with the bottom pivots of the verges, one verge being allowed to fall into its working position while the other one is lifted from engagement with its crown wheel.
To allow for the variation in the length of the days and nights the weights on the foliot balances are shifted along the arms at intervals of 15 days. The clock has a single hand mounted on a rotating inner dial which is tapped with a number of holes, into any one of which the pin for discharging the alarm can be screwed.

The clock strikes the 'hours' in the usual Japanese sequence of 9, 8, 7, 6, 5, 4 from midnight to noon and again from noon to midnight, and gives a single stroke each half 'hour'.

194 Japanese 'lantern' clock

This clock is provided with a special striking arrangement whereby the last two strokes occur in quick time to indicate that the clock has finished striking, thus reproducing mechanically the manner in which the time signals were formerly struck by hand.

To obtain this special action, there is an extra striking hammer, operated by a series of pins mounted on the count wheel, which gives the final strokes.

In other respects the clock is similar in general to the iron clock exhibited adjacently, except that it has brass plates and wheels, and a dial rotating behind a fixed pointer. It was probably constructed early in the nineteenth century.

195 Japanese 'lantern' clock

This clock, which probably dates from the early nineteenth century, is controlled by a balance wheel and spring, and the balance wheel is provided with adjustable weights for regulating its period of oscillation. The clock strikes on the usual Japanese system and is also fitted with an alarm. The dial rotates behind a fixed pointer and the hour-marks are adjustable in a sliding ring in the dial to allow for the variation in the length of the hours at different seasons.

Two small square apertures below the dial show characters which, when combined, indicate the day of the sexagenary period, a system of reckoning in cycles of 60 which was introduced into Japan from China in AD 602.

Bracket Clocks

196 Japanese 'bracket' clock

(*See Plate 10*)

This striking clock has a rotating dial provided with adjustable indicators for showing the time on the old Japanese system in which the periods of daylight and of darkness are each divided into six intervals.

A fixed hand is employed and the dial rotates in a clockwise direction once a day. The characters indicating midday and midnight are fixed at diametrically opposite positions on the dial, but in order to allow for the difference in the lengths of the day and night 'hours' at different seasons of the year, each remaining hour-mark is mounted on a small plate which slides in a grooved ring in the dial.

The clock is spring-driven and controlled by a verge escapement and 'bob' pendulum. It strikes on the usual Japanese system, the sequence of strokes from midnight to noon being 9, 1, 8, 2, 7, 1, 6, 2, 5, 1, 4, 2.

197 Japanese bracket clock

This clock resembles the adjacent example (Catalogue no. 196) in most respects, but differs from it in being controlled by a balance-wheel and spring, and provided with indicators for the whole 'hours' only. It strikes also at the whole 'hours' only, the sequence of strokes being 9, 8, 7, 6, 5, 4, corresponding with the numbering of the Japanese 'hours'.

Pillar Clocks

198 Japanese pillar clock

The timekeeping of this clock is controlled by a foliot balance, and the movement is of iron. As in other pillar clocks, the time is shown by means of a pointer attached to the driving weight which moves past a vertical scale of hours. The hour-marks are individually adjustable.

199 Japanese clock

This nineteenth-century clock is of the pillar type, in which the time is indicated by the vertical position of the weight which drives the clock. The weight carries an index moving over a graduated scale, which covers the period of one complete day and night.

To allow for the unequal time periods employed during the days and the nights at different parts of the year, the graduated scale is changed monthly.

This clock is controlled by a verge escapement employing a 'bob' pendulum.

200 Japanese clock

This clock resembles the adjacent one, the time being indicated by the height of the driving weight, which carries an index moving over a graduated scale. In this clock, however, the scales for all the months of the year are combined upon a single plate, and the index connected with the weight is movable horizontally across its bar so as to bring it opposite to the scale of hours for the appropriate month.

The variation in length of the Japanese day and night 'hours' is well shown by this plate. It will be seen that in midwinter the day and night 'hours' are of almost equal length, while in midsummer the day hours are some two and a third times as long as the night hours. It must therefore have been customary to count a considerable period of twilight at each end of the day as belonging to the day, so that in midwinter 'day' and 'night' would each last for some 12 European hours, while at midsummer 'day' would last almost 17 European hours and 'night' a little over seven.

201 Japanese 'pillar' clock

This clock is of special interest in being fitted with a 'pirouette' or geared balance-wheel.

The verge carries a toothed sector which gears with a pinion coaxial with the balance-wheel.
This device was employed by Huygens in his pioneer watch with balance-spring made in 1675; it has the advantage that the balance can have a large arc of swing, but it introduces considerable friction which is detrimental to good timekeeping.
The design of Japanese clocks owes a good deal to Dutch influence, and it is possible that the clock exhibited, which is probably about 150 years old, can be regarded as a descendant of the first Huygens watch.

Table-Clocks

202 Japanese clock with porcelain case

In this type of Japanese clock the mainspring drives the timekeeping mechanism through a cord which it unwinds from a cylindrical drum, and the hour-indicator is attached to a point on this cord. The hour-marks themselves are adjustable in a groove to allow for the different lengths of the hours at different seasons of the year according to the old Japanese system of time-reckoning. The indicator traverses the whole length of the scale in a day and night and is then drawn back again as the mainspring is wound up.
The timekeeping is controlled by a verge escapement with balance and spring.
The porcelain case bears pictures of the animals with which the various hours of the day and night were associated on the Japanese system.

203 A Japanese painting of a clock

The clock which the lady is winding is weight-driven and controlled by a single foliot balance with adjustable weights. It appears to have a fixed dial in front of which an hour-hand rotates.
The painting is on silk, and is by Nishikawa Sukenobu (1671-1751).

204 Chinese table-clock

A transitional type of clock in which the dial carries a set of arabic numerals as well as the Chinese signs of the zodiac, which serve as hour numerals.
The clock is driven by a mainspring through a fusee and is controlled by a verge escapement with balance and spring. It indicates equal hours according to the modern European system.
It is provided with an adjustable alarm released by an arm falling off a snail.

6 Watches

The watches are grouped mainly according to the type of escapement they employ, but other groups show stop-watches, chronometer watches, repeaters and musical repeaters, winding mechanisms, etc.
Electric watches are included with electric clocks in Chapter 7.

205 Colour transparency: of a mid-sixteenth-century German verge watch.

206 Two colour transparencies: of a mid-sixteenth-century Italian painting showing a man holding a watch similar to catalogue no. 205.

207 Diagram of verge escapement: the verge, which is also known as the crown wheel or vertical escapement, is the earliest form of escapement definitely known to have been employed. It was used for controlling clocks as early as the fourteenth century and was employed in the portable timekeepers, known as table-clocks, which came into use in the sixteenth century and developed into the pocket watch in the early seventeenth century.
As shown in the accompanying sketch it consists of a 'crown' wheel with pointed teeth which engage with two projections or 'pallets' on the axis of the balance wheel. In action a tooth presses against a pallet and imparts an impulse which causes the balance to rotate until the pallet has moved through such an angle that the tooth ceases to engage with it, and the wheel is then free to move until another tooth engages with the second pallet. As the two pallets engage with opposite sides of a diameter of the crown wheel, this tooth is moving in an opposite direction to the second pallet and its first action is to bring the pallet and balance to rest, during which process the wheel recoils a little. An impulse is then imparted to the second pallet and the balance made to rotate in the opposite direction. The successive engagements between the wheel teeth and the pallets result in an oscillating motion being imparted to the balance. This action can be seen in the large example of this escapement included in the turret clock formerly in Dover Castle (catalogue no. 136), exhibited in this Gallery.
In the earliest pocket watches there was no controlling spring on the balance, but about 1660 Hooke invented the balance spring which made accurate timekeeping possible, and about 1675 Huygens showed how to apply it successfully.

The collection of verge watches shown illustrates various modifications of the arrangements of the movements, the types of watch cases, and the ornamental features of the pillars, plates, and of the cocks, the pieces which carry the upper bearing of the balance. It will be noticed that the extent of ornamentation was considerably reduced towards the end of the eighteenth century.

208 Verge watch: without balance-spring, with bristle regulator for the balance and stackfreed for equalising the pull of the mainspring. German. Sixteenth century.

209 Late sixteenth-century German oval watch: with iron movement and stack-freed controller.

210 English verge watch: of about 1630 by Richard Jackson.

211 Verge watch: of about 1660 by David Lestourgeon, Rouen. (*See Plate 7b*)

212 Verge watch: by Hen. Jones, London, in silver pair case.

213 Verge watch: in triple case by Dan. Quare, London. No. 4559 About 1700.

214 Verge watch: in silver repoussé pair case, by Thomas Taylor, Holborn. About 1700.

215 Verge watch: in silver pair case, by Ed. Wrench, Chester. About 1700.

216 Verge watch: in pair case, by T. Tompion and E. Banger. No. 3435. Early eighteenth century.

217 Verge watch: by Thos. Mudge, London. No. 31. Eighteenth century.

218 Verge watch: in silver inner case, by Thos. Dwerrihouse, Garston, with silver plate and cock. No. 166. Hall-mark 1774.

219 Verge watch: by Geo. Graham, London. Chester hall-marked case. No. 5175. 1779.

220 Verge watch: in pinchbeck repoussé pair case, by Josh Emery, London. No. 797. About 1780.

221 Verge watch: with skeleton plate, by Imison, London. No. 23. Hall-mark 1786.

222 Verge watch: in silver pair case, by Wm. Finch, Halifax, with silver cock. Late eighteenth century.

223 Verge watch: in silver pair case, by Jos. Dumbill, Prescot. Silver top plate. No. 416. Early nineteenth century.

224 Verge watch: with three-quarter plate movement, in silver case, by John Weston, London. No. 1842. 1842.

225 Verge watch: in silver octagonal case, by Berthoud, Paris. Late eighteenth century.

226 Verge watch: in silver case, by Rosé, Soleure, with large balance wheel. Early nineteenth century.

227 English verge watch movement: by T. Tompion, London, with tulip pillars, pierced and engraved balance cock, and tangent screw arrangement for setting up the mainspring. Late seventeenth century.

228 English verge watch movement: by Tyler, London. No. 368, with skeleton top plate and pierced barrel cover. Eighteenth century.

229 English verge watch movement: with hare and snail indicator for the regulator, inscribed 'Ann Raven'. Early nineteenth century.

230 English verge watch movement: by Geo. Yonge, London, with arrangement for setting the hands from the back and special marking for guidance when winding the spring or setting the hands. About 1800.

231 Dutch verge watch: by John van Ceulen, The Hague. About 1695.

Debaufre's escapement

232 Diagram of Debaufre's escapement: This escapement, which was invented by Peter Debaufre about 1700, may be regarded as a modification of the verge escapement in which the recoil of the verge is eliminated.

There are two escape wheels with pointed teeth, mounted on a common axis and situated one on each side of the balance staff, and the latter carries a small pallet piece which is cut away on one side to give an inclined plane impulse surface. In the diagram a tooth of the nearer wheel is shown engaging with this surface and as the tooth moves upward the balance receives an impulse urging it counter-clockwise. When the tooth slips off the impulse face the wheel advances until the next tooth of the further wheel engages with a flat locking face on the bottom of the pallet. On the return swing of the balance this tooth is unlocked and in turn imparts an impulse to the pallet, but as the action is now on the opposite side of the balance staff the impulse impels the balance in a clockwise direction.

The elimination of any recoil is a considerable advantage and dispensed with the necessity of a fusee. In the early part of the nineteenth century

a number of going barrel watches with this escapement were made, more especially at Ormskirk, Lancashire, where it was known as the 'club-footed verge'.
Some examples of watch movements with this escapement are shown adjacently.

233 Watch: with Debaufre type escapement, with two pin wheels, by Thos. Harrison, Liverpool. No. 109. About 1760.

234 Watch: with going barrel and club-footed verge escapement, by James Ryland, Ormskirk. No. 646. About 1800.

235 Watch movement: with club-footed verge escapement, by Jas. Houghton, Ormskirk. No. 1260.

236 English watch movement: by Robert Roskell, Liverpool. No. 1896, with club-footed verge escapement. Early nineteenth century.

237 Watch: in silver case, by J. S. Magnin, with special escapement. Late eighteenth century.

Virgule escapement

238 Diagram of Virgule escapement: this form of escapement is now obsolete, but it was formerly used to a limited extent, especially towards the end of the eighteenth century. The credit for its invention and development has been claimed for the Abbé Hautefeuille, Caron, Lepine, and Lepaute.
As shown in the diagram the escape wheel has a series of curved teeth at the ends of which are vertical projections. On the axis of the balance wheel there is a hook or comma-shaped piece from which the escapement derived its name, virgule being the French equivalent of comma.
In the small diagram a vertical projection of a tooth is shown imparting an impulse to the hook. When the tooth escapes from the hook, the wheel advances and the next tooth locks against the outside of the hook. During the return swing of the balance wheel, this tooth passes into the small cylindrical cavity shown and in so doing imparts to the balance a small subsidiary impulse known as the small lift, the main impulse, previously described, given to the hook being the great lift.
An example of a watch movement with this escapement is shown nearby. (Catalogue no. 239.)

239 French centre-seconds watch movement: with virgule escapement, and skeleton upper plate. About 1800.

Watches with 'Pendulum' Balances

In these watches the rim of the balance wheel is covered by the cock and a small circular weight is added to the balance arm to produce the appearance of a vibrating pendulum.

240 German verge watch: by George Seydell, Coln an der Sprre, with pendulum balance and calendar dials.

241 Verge watch: by D. B. D. Neveren, with pendulum balance wheel. Hall-mark 1784.

242 Verge watch: in silver repoussé case, by Pieter Thijmen, Gouda, with pendulum balance wheel.

243 Verge watch: in silver pair enamelled repoussé case, by 'Viet, Rotterdam', with pendulum balance wheel.

Alarm and striking watches

244 French seventeenth-century alarm watch: by André Pichon à Lyon.

245 Alarm watch: with verge escapement in pinchbeck consular case, by Saml. Toulmin, Strand. No. 2495. Late eighteenth century.

246 Verge alarm watch: in gold-plated case, by Meuron & Co. French. No. 18595. Late eighteenth century.

247 German stackfreed clock-watch: with dumb-bell foliot.

248 Clock watch: in pinchbeck tortoise-shell case, with verge escapement, by Nath. Barrow, London. Late seventeenth century.

249 Clock watch: in silver pair case, with verge escapement, by John Martin, London. Late seventeenth century.

250 Verge clock watch: and repeater in gold case, plate engraved, 'Pour Eugenio Ferro in Treviso'.

251 Jaeger-le Coultre alarm wrist-watch: 1953.
See also catalogue no **489**.

Cylinder escapement

252 Diagram of cylinder escapement: the cylinder escapement was invented by George Graham about 1720, and may be regarded as an improvement of an escapement invented by Tompion in 1695. As the axis of the escape wheel is parallel to that of the balance this escapement is termed 'horizontal' in distinction from the verge or vertical escapement in which the escape wheel axis is at right angles to the balance axis.
As shown in the diagram, there is an escape wheel with a series of pointed teeth which engage with an incomplete cylindrical shell, the latter being coaxial with the balance wheel. The inclined faces of the teeth engage with the lips of the shell and impart impulses which maintain the balance in vibration.

It will be noted that the action resembles that of the dead-beat escapement for clocks in that the locking faces are circular and there is no recoil of the escape wheel.
This escapement was first employed by English makers, who used a brass escape wheel and, in their best movement, ruby cylinders, without, however, attaining any marked success. Later it was used in Switzerland with much better results in conjunction with a small steel escape wheel, and until about the end of the nineteenth century it was very extensively used in the watches known as 'Geneva' watches.
A number of watches with this escapement are shown, and there is a model, on a magnified scale, in an adjacent case (see catalogue no. 403).

253 Cylinder watch: in silver case, by Geo. Graham London. No. 5223. Eighteenth century.

254 Cylinder watch: in silver repoussé pair case by Just. Vulliamy, London. No. nxo. Eighteenth century.

255 Cylinder watch: in pinchbeck inner case, tortoise-shell outer case, by L. Kendall, London. Eighteenth century.

256 Cylinder watch: in silver pair case, by Tho. Mudge and W. Dutton, London. No. 597. Hall-mark 1759.

257 Cylinder watch: in enamelled consular case, by Josiah Emery, London. No. 2438. About 1780.

258 Cylinder watch: by Thos. Reid, Edinburgh. No. 2520. About 1800.

259 Cylinder watch: in silver inner case and tortoise-shell outer case, by Barwise, London. Steel escape wheel. No. 3275. Hall-mark 1803.

260 Cylinder watch: in silver case, with going barrel. Hall-mark 1839.

261 Cylinder watch: in silver case, by Breguet. 'Subscription' watch with hour hand only. No. 445.

262 Cylinder watch: in silver case, by Breguet et Fils. 'Subscription watch. No. 1350.

263 Cylinder watch: in enamelled gold case, La Croix, Geneva. No. 5666.

264 Cylinder watch: in gold engraved case, by Jodin, Paris. No. 352. About 1800.

265 Cylinder watch: in gold repoussé case, by Moulinié, Bautte & Moynier, Geneva.

266 Flat watch movement: with horizontal escapement, F. & A. Meylan, Geneva. No. 23093.

267 English cylinder watch movement: by Geo. Graham, London. No. 4796. Middle eighteenth century.

268 Cylinder watch movement: by Jeffrys & Jones, London. No. 436, with steel escape wheel. About 1800.

269 Thin Swiss cylinder watch movement: about 1800.

270 Cylinder watch movement: by Jean Antoine Lepine, Paris. About 1800. Constructed according to the thin 'Lepine' calibre, introduced by this maker, in which the top plate is replaced by bars.

Breguet's cylinder escapement

271 Diagram of Breguet's cylinder escapement: this diagram shows a special form of cylinder escapement used by Breguet to a limited extent in the early part of the nineteenth century.
The incomplete cylindrical shell overhangs below the bottom pivot, an arrangement which permits the more simple shape shown for the escape wheel teeth. The acting surface consists of a shaped ruby.
This escapement is employed in the adjacent clock watch made by Breguet in 1797-8 (catalogue no. 272).

272 Clock watch: with ruby cylinder overhanging below bottom pivot, in gold case, by Breguet. No. 300. 1797-8.

Duplex escapement

273 Diagram of duplex escapement: this escapement was introduced towards the end of the eighteenth century and has been credited to various inventors. In the early years of the nineteenth century it was extensively used in high-class watches.
It received its name from the two escape wheels, which were employed in its original form, one for effecting the locking and the other for the impulse, but these two wheels were afterwards made as one wheel with two sets of teeth.
As shown in the diagram a set of flat pointed long teeth successively engage with a notched jewelled roller mounted on the axis of the balance wheel. When the balance so moves that the notch allows the escape wheel to advance, one of the second set of teeth, which project upward, engages with a jewelled pallet mounted on a projecting piece secured to the axis of the balance wheel and imparts an impulse to the latter. At the end of this impulse the wheel is free to move until a long tooth falls on the jewelled roller and the wheel is again locked.
It will be seen that an impulse is given to the balance on alternate vibrations only and that, in addition to the main impulse, the balance

receives a subsidiary impulse from the long teeth engaging with the notch. These two impulses are known as the great lift and small lift respectively.
Examples of watches with this escapement are shown adjacently, and a large-scale model may be seen in a neighbouring showcase (see catalogue no. 408).

274 Duplex watch movement: by Recordon, with compensation curb. No. 7122.

275 Duplex watch: in silver hunter case, by Vulliamy, London. No. xxam. Hall-mark 1823.

276 Duplex watch: in silver case, by Thos. Earnshaw, 119 High Holborn, London. No. 4521. Hall-mark 1824.

277 Duplex watch: in silver hunter case, by Molyneux & Sons, London. No. 1368. Hall-mark 1830.

278 Duplex watch: in silver case, by James McCabe, London. No. 2598. Hall-mark 1833.

279 Swiss duplex three-quarter plate watch movement: with fusee, made by Grandjean Père et Fils. About 1830.

280 Swiss going-barrel watch movement: with duplex escapement and steel escape wheel. Middle nineteenth century.

281 American going-barrel keyless duplex 'Addison' watch movement: of about 1890 ('Waterbury' type).

Lever escapements

282 Diagram of rack-lever escapement: this escapement was patented by Peter Litherland in 1791 and was employed to some extent on English watches about the beginning of the nineteenth century. A similar escapement had, however, been invented by the Abbé Hautefeuille in France as early as 1722.
An anchor carrying the pallets is secured to a lever at one end of which there is a toothed rack gearing with a pinion on the axis of the balance. The arrangement is subject to the disadvantage that the balance is always in connection with the lever and pallets, that is, it is an 'undetached' form of escapement.
Examples of watches with this escapement are shown adjacently.

283 Rack-lever watch: in pinchbeck pair case, by P. Litherland & Co., Liverpool. No. 306. About 1800.

284 Watch movement: with rack-lever escapement, by R. Roskell. No. 8225.

285 Lever watch movement: with rack lever straight-line escapement, by P. Litherland & Co., Liverpool. No. 27. Early nineteenth century.

286 Diagram of crank roller escapement: this form of lever escapement was introduced about the end of the eighteenth century and was used considerably in the early part of the nineteenth century. The invention has been claimed for both Edward Massey and George Margetts.
Mounted on the balance staff there is a short cylindrical piece, known as the roller, carrying two projections between which there is a jewel pin. This pin engages with a notch at the end of the lever on which the anchor carrying the pallets is mounted. The motion of the lever is restricted by banking pins, and during the greater part of its vibrations the balance is free from engagement with the lever. This feature constitutes a detached escapement, and gives great advantage in comparison with the undetached form of rack lever escapement.
In some cases a finger or tooth projecting from the roller is employed instead of the jewel pin shown in the diagram.
Specimens of watch movements with this escapement are shown adjacently.

287 Crank-roller lever watch: with Arabic numerals on the dial, by S. Weatherilt, Liverpool. No. 741.

288 Lever watch movement: with crank roller, by M. I. Tobias & Co., Liverpool. No. 8386. Early nineteenth century.

289 Diagram of English lever escapement: this form of escapement came into use in the early part of the nineteenth century, and it is the form which has been most extensively used in English hand-made watches.
Its action is described in connection with a model, on a magnified scale, shown in an adjacent case (see catalogue no. 405).
The lines joining the pallet staff with the balance staff and the escape wheel axis respectively are at right angles and it is known as a right-angled escapement in comparison with the straight-line escapement in which these three axes are in the one line, as is usual in Swiss and American watches with club-shaped teeth.
Examples of watch movements with this escapement are shown adjacently.

290 Lever watch: in silver case, by Thos. Earnshaw, London. No. 4776. Hall-mark 1831.

291 Bar movement: with straight-line lever escapement. No. 16670.

292 Lever watch: with a Geneva stop to prevent over-winding. In gold case, hall-mark 1830.

293 Diagram of club-tooth lever escapement: this form of escapement was first used extensively by the Swiss and is now in general use for pocket watches except the highest grades of English-made watches.

As shown in the diagram, the tips of the teeth take the form of inclined planes and the impulse is obtained in two stages, first by the engagement of the planes of the teeth with an edge of the pallet and next by the engagement of the teeth with the impulse planes of the pallets.

The club-tooth has the advantage of retaining oil better than the pointed tooth, of requiring less 'drop', as the free motion of the wheel between engagements with the pallets is termed, and also of being less fragile, and its employment has increased considerably during the present century.

Movements with this escapement are shown adjacently, and there is a large-scale working model in a neighbouring showcase (catalogue no. 406).

294 Lever watch: in silver case, by 'Piguet et Meylan'. No. 46133.

295 Lever watch movement: with club-toothed escape wheel, and forked lever banking on the escape wheel arbor, by Robt. Roskell, Liverpool. No. 32224. About 1830.

296 Lever watch movement: with club-tooth escape wheel and straight-line escapement, by United States Watch Co. No. 32659. Inscribed 'John F. Sylvester, N.Y.'. About 1870.

297 Geneva lever watch movement: with steel club-toothed escape wheel and going-barrel. The bars engraved.

298 Miniature lever watch: by Piguet & Meylan. Presented by HM Queen Mary.

299 Movement of Jaeger-le Coultre watch model 72: (1953) 'The smallest watch in the world'.

Special levers

300 Lever watch movement: by Litherland, Davies & Co., Liverpool. No. 11197, with dead-beat anchor escapement, large balance wheel beating seconds, and crank roller.

Stop-watches and pocket chronographs

301 Stop-watch: by Martin, Royal Exchange, London, with jump quarter-seconds. Late eighteenth century.

302 Cylinder stop-watch: by Geo. Graham. No. 6296. Hall-mark 1748.

303 Centre seconds cylinder stop-watch: by Ellicott, no. 8415.

304 French verge stop-watch: with centre seconds-hand, by Le Roi. About 1750.

305 English verge watch movement: by Kenneth Maclennan, London. No. 735, with centre seconds and stop work acting on the escape wheel. About 1800.

306 English lever watch movement: with independent centre seconds by Thos. Tarleton, Liverpool. No. 7271. Middle nineteenth century.

307 'Geneva lever' watch: with independent centre seconds, in silver case. No. 10943.

308 Independent centre seconds chronograph: with cylinder escapement and two complete sets of hands, one set for chronograph mechanism and one for time.

A collection of stop-watches and chronograph watches

309 English stop-watch movement with verge escapement: made by J. Stirling, London, about 1780. The movement can be stopped at will by sliding a small piece which presses a light arm against a wheel on the seconds-hand arbor.

310 English stop-watch movement with verge escapement: made by Charles Wilson, London, hall-mark 1784. Carries a centre seconds-hand and a small circle for minutes and hours. Stopping mechanism similar to that of 309.

311 English movement with cylinder escapement: made by Barraud, London, about 1800. Main circle reads minutes and hours, one circle 60 seconds and one circle 4 seconds divided into fifths of a second. Stopped by a light arm which presses on the escape wheel.

312 Modern Swiss movement with lever escapement: a complicated movement, combining fly-back chronograph, quarter repeating mechanism and calendar showing day of the week, day of the month, month and phases of the moon.

313 English chronograph movement: made by Arnold and Dent, London, about 1840. There are two circles showing minutes and hours, one of which can be started and stopped independently of the other.

314 Swiss independent centre seconds chronograph movement: made probably about 1870. The centre seconds-hand beats

whole seconds, there is a circle indicating minutes and hours on the chronograph mechanism, and another circle showing the time.
The chronograph hands have to be set for each reading.

315 Modern Swiss 'split-seconds' chronograph movement: Two centre seconds-hands travel together, and fly back as required, but one of them can be stopped and then when released flies either backwards or forwards to meet and travel with the main seconds-hand.

316 Inking chronograph: by O. Vivier, London. Hall-mark 1877. Indicates in ink, on the dial, by means of a start-and-stop centre hand. Minutes are indicated by a separate hand on a concentric minute circle.

Chronometer Watches and Watches with Temperature Compensation

317 Cylinder watch: with compensator acting on curb pins, by John Arnold, London. No. 1. Late eighteenth century.

318 Cylinder watch: with curb compensation, by Jno. R. Arnold, London. No. 3636. Early nineteenth century.

319 English Duplex watch movement: by S. and C. Joyce, London. No. 1185. Early nineteenth century. With compensation curb in which the curb pins are at the ends of bimetallic strips.

320 Chronometer watch: by Thomas Earnshaw, with curb temperature compensating device. No. 728. About 1800. The case is not original.

321 Pocket chronometer movement: made by John Arnold, London, towards the end of the eighteenth century, with compensation balance, helical balance spring, and detent escapement patented by him in 1775-82. Maker's no. 70/371.

322 Chronometer watch: in silver case, by John Arnold & Son, London. No. 360/661. Late eighteenth century.

323 Chronometer watch: in silver case, by Thos. Earnshaw, London. No. 422. Early nineteenth century.

324 Chronometer watch: in silver case, by Thos. Earnshaw, London. No. 837. Hall-mark 1825.

325 Chronometer watch: in silver case, by 'J. R. Arnold, Chas. Frodsham, 84 Strand, London'. With half-plate movement. No. 6530. Hall-mark 1833.

326 Watch movement: with chronometer escapement, by Dimier Frères et Cie, Fleurier. No. 28981.

327 Gold repeating watch: no. 2978, by Breguet, with curb compensator and parachute.

328 Watch: by Breguet et Fils, no. 4336, with lever escapement and compensation balance.

329 Swiss lever watch: with tourbillon movement.

330 Tourbillon watch: early twentieth century, with compensation balance and overcoil spring.

331 Karrusel deck watch: by Richard Thorneloe, Coventry, late nineteenth century.

Special dials, calendars, centre seconds, etc.

332 English watch: of about 1660, by William Crayle in the Strand, with wandering hour-figure (*see Plate 7a*).

333 Verge watch: in silver pair case, by Jno. Harrison, London. Centre seconds. No. 400. Hall-mark 1784.

334 Verge watch: by Ralph Gout, London, combined with pedometer. No. 224. About 1800.

335 Calendar watch: with lever escapement, by Richd. Clarke, London. No. 124. Early nineteenth century.

336 Cylinder watch: in silver case, by Vaucher, with hours shown in aperture under pendant. No. 3478.

337 Calendar watch: in silver case, with cylinder escapement; balance wheel under the dial. Hall-mark 1860.

338 Keyless lever watch: with centre seconds, beating tenths of seconds, by Wm. Williams, Bury. No. 19289. 1890.

339 Astronomical watch: no. 3043, by Geo Margetts, London, with universal tidal dial.

340 Watch: made for the Turkish market about 1800, by George Prior, London.

341 Half-hunter lever watch: with calendar at back giving days of the week and of the month.

Regulating mechanisms

342 English 'Puritan' watch: of about 1650, with later balance-spring adjustable by worm.

343 Verge watch: by Jacobus Markwick, London, with Barrow-type regulator.

344 Verge watch: with tangent-screw regulator, by W. I. Ward, London. No. 2532. Hall-mark 1794.

345 Verge watch: with 'hare and snail' regulator, by Wllm. Smith, London. No. 9709. Early nineteenth century.

346 Verge watch: with visible rack regulator, by Thierry, Caen.

Winding devices

347 Swiss lever watch movement: of about 1870, by U. Humbert Ramuz, Chaux de Fonds, with rack keyless mechanism with 'pumping' action of form patented by Edward Massey in 1814.

348 English going-barrel keyless cylinder watch movement: by Viner & Co., London. No. 1988, with rack and pinion 'pumping' keyless mechanism which does not operate the hands. Early nineteenth century.

349 Swiss keyless cylinder watch movement: by A. B. Savory, with 'pumping' keyless mechanism actuated by a chain; the hands are set by a milled nut on the cannon pinion. Early nineteeenth century.

350 Verge watch movement: by Bright & Sons, Sheffield. No. 12962, with 'pump' winding arrangement actuated by a chain. Early nineteenth century.

351 English lever going-barrel keyless watch movement: of about 1830, by Arnold and Dent, London. No. 4667. A stem with bevel gear was employed for winding and the hands were set by an ordinary key.

352 English lever going-barrel keyless watch movement: of about 1870, with the rocking bar keyless mechanism generally employed in English watches, which was patented by Gustavus Huguenin in 1855.

353 Swiss watch: with unusual form of keyless winding mechanism. About 1850.

354 Lever watch movement: by Thos. Russell & Son, with up-and-down indicator for winding. No. 108241. Nineteenth century.

355 Self-winding watch: No. 289, by Loehr (of Vienna), about 1880.

356 Harwood self-winding wrist watch: of about 1930.

357 Jaeger-Le Coultre automatic wrist-watch: (1953) with reserve power indicator.

358 Movement of Jaeger-Le Coultre automatic wrist-watch: (1953), showing self-winding mechanism.

Repeaters and musical repeaters

359 Verge quarter-repeating watch: by Thierry à Caen. No. 401.

360 Verge repeating watch: in pinchbeck-shagreen pair case, by Jno. Kentish, London. No. 908. Eighteenth century.

361 Quarter repeating watch: with horizontal escapement, in gold case. English. No. 3431. Hall-mark 1813.

362 Verge repeating watch: in silver case, by Berthoud, Paris. No. 976.

363 Verge repeating watch: in gold case, by Breguet, Paris. About 1800.

364 Repeating watch: with cylinder escapement in gold case, by Lacroix, Turin. No. 8044. 1833.

365 Repeating watch: with cylinder escapement, parachute, and curb compensator, in gold case, by Breguet. No. 357. About 1800.

366 Repeating watch: with cylinder escapement, in silver case, by Breguet. No. 4128.

367 Half-quarter repeating watch: with cylinder escapement, in silver case, by Thos. Earnshaw, 119, High Holborn, London. No. 4502. Hall-mark 1823.

368 Musical repeating watch: with cylinder escapement, in silver case, by Breguet. No. 225. About 1800.

369 Musical repeater: with cylinder escapement, enamelled. No. 8594.

370 Repeating watch: with cylinder escapement, in silver case, by Ellicott, London. No. 5083.

371 English quarter-repeater cylinder watch movement: with steel escape wheel, by Robt. Roskell, Liverpool. No. 10073. Early nineteenth century.

372 English quarter-repeater watch movement: with duplex escapement, by Viner & Co., London. No. 2021. About 1830.

373 Swiss repeater cylinder watch movement: with fusee, brass escape wheel, and pierced bridge balance cock, made by Terroux, l'âiné, Geneva. 1779.

374 Quarter-repeater going-barrel cylinder watch movement : of French or Swiss make, with brass escape wheel, balance wheel under the dial, and fitted with two bells. About 1800.

375 Swiss minute-repeater cylinder watch movement: with repeating work mounted at the back. Middle nineteenth century.

376 Swiss musical watch movement: with cylinder escapement and a disc carrying pins which engage with short steel springs and give the notes required. About 1800.

377 Quarter repeating watch : by Quare, London. No. 446. About 1700.

378 Quarter repeating lever chronograph watch.

379 Half-quarter repeating chronometer watch movement: by Thos. Earnshaw.
See also Catalogue Nos. **492** *and* **493.**

7 Chronometers

Chronometers are mechanical timekeepers specially designed to keep accurate time on board ship.
The position of a ship at sea is known when its latitude and longitude have been determined. The navigator can find his latitude by observing the sun or stars, but to find his longitude he must in addition know the standard time at which the observation was made, i.e., the time at some place whose longitude is known. The only practicable method of finding standard time at sea is to carry on board ship an accurate timekeeper; before accurate marine timekeepers were available navigators on long ocean voyages could only very roughly estimate their longitude, and mistaken estimates caused many shipwrecks.
John Harrison in 1728-59 was the first to construct instruments which would keep sufficiently accurate time on board ship; he was quickly followed by others, such as Mudge, Arnold and Earnshaw, who left the chronometer in a form which has since changed relatively little in 100 years.
The Museum Collection includes photographic transparencies showing Harrison's four pioneer marine timekeepers, examples of chronometers by Arnold, Earnshaw and other early and modern makers, together with a collection of exhibits illustrating the various methods which have been employed for overcoming the effect of changes of temperature on the rate of chronometers.

380 Five transparencies showing Harrison's marine timekeepers

The left-hand photograph (1) shows the first of the series of four marine timekeepers designed and constructed by John Harrison between 1728 and 1759.
The first timekeeper, completed in 1735, is essentially a clock designed to be unaffected by the motion of a ship.
Its two balances are geared together by a system of wires making them rotate in unison but in opposite directions, and the effect of temperature is compensated by varying the effective length of the balance-springs, the instrument being the first balance wheel timekeeper to employ any kind of temperature compensation. It utilises Harrison's 'Grasshopper' escapement and his maintaining power.
The second timekeeper, photograph (2), completed in 1739, is similar in many respects, but employs a remontoire re-wound every $3\frac{3}{4}$ minutes.
The third timekeeper, photograph (3), was finished in 1757, and has only a single spiral balance-spring whose effective length is varied by a bi-metallic 'compensation curb': the first ever constructed. Its remontoire is re-wound every 30 seconds.

The fourth timekeeper, shown in the two photographs on the right, is much smaller than the earlier three, being in the form of a large watch about 5 inches in diameter.

It has a single balance-wheel, a modified form of verge escapement, and its remontoire operates every $7\frac{1}{2}$ seconds.

It won the £20,000 prize offered by the British Government for an accurate marine timekeeper, and when tested on a voyage to the West Indies and back its error was only 15 seconds after five months.

All four timekeepers are now in the National Maritime Museum, Greenwich.

[See *The Marine Chronometer* by R. T. Gould.]

381 Mezzotint of John Harrison

Harrison was born at Foulby, near Pontefract, Yorkshire in 1693, but spent most of his early life in Barrow-on-Humber, Lincolnshire. He moved to London in 1735 and lived there until his death in 1776.

The mezzotint is by L. Tassaert from an oil painting by T. King, and was published in 1768.

On the table, near Harrison's right hand, is his small prizewinning fourth marine timekeeper; in the background, on the left, is the much larger third marine timekeeper; and on the right his 'gridiron' compensation pendulum for clocks.

382 Marine chronometer

(See Plate 8)

A two-day chronometer, no. 63, by John Arnold and Son. Late eighteenth century. It has an Arnold-type detent escapement and helical balance-spring, the latter being of gold. The compensation balance is of the usual Arnold type.

383 Marine chronometer

A two-day marine chronometer, no. 43/133, by John Arnold and Son with Arnold's detent escapement. It was made about 1800 but was modified at a later date and is now fitted with a compensation balance of a form patented by J. R. Arnold in 1821.

In this balance there is a horizontal bi-metallic cross bar, consisting of flat strips of brass and steel at the ends of which are vertical arms carrying weights. The bending of the bi-metallic arm due to a rise of temperature causes the weights to approach the centre of the balance

At right angles to the bi-metallic bar there is a diametral arm carrying timing screws.

384 Chronometer

A small one-day marine chronometer, no. 488, by J. R. Arnold, made during the early part of the nineteenth century and including the helical form of balance-spring and the detent escapement patented by John Arnold, the father of J. R. Arnold, in 1775 and 1782 respectively.

The escapement differs but slightly from that used in modern chronometers. In this example the impulse faces of the teeth of the escape wheel are of epicycloidal form and the detent moves towards the centre of the wheel to unlock.

The compensation balance is of the bi-metallic rim type and consists of two arcs made up of strips of brass and steel rigidly attached, the former being on the outside. These two arcs are mounted on a diametral arm and the necessary compensation is arranged by means of two small adjustable weights on the rim of the balance at the free ends of the arcs. Two timing screws are employed and are fitted at the ends of the diametral arm.

385 Marine chronometer

A one-day chronometer, no. 532, by John R. Arnold, London, made in the early part of the nineteenth century, with an Earnshaw detent escapement.

An up-and-down indicator is provided to show when winding is required and this is operated by means of a pinion on the fusee arbor.

A special feature is the provision of an arrangement for winding without having to turn the movement upside down in accordance with the general practice. The winding square is at the side of the dial, on an arbor passing to a wheel at the bottom of the case which, when the winding square is pushed down, engages with a larger wheel squared on to the fusee arbor. Normally the two wheels are out of gear.

The balance and balance-spring now fitted are not the original ones.

386 Marine chronometer

A one-day chronometer, by Thomas Earnshaw, made in the early part of the nineteenth century, with a detent escapement of the type which was introduced by Earnshaw about 1782 and is still generally employed in marine chronometers.

The balance is of the form first constructed by Earnshaw, but it has been modified by the addition of a device invented by Sir George Airy about 1871. This consists of a diametrical bar carrying springs on the extremities of which small weights are mounted. The latter are kept in close contact with the inside of the rim of the balance, and consequently move inwards or outwards with the rim. They thus virtually form part of the balance weights, but as the bar carrying them can be readily rotated on the balance staff and their distances from the free ends of the half rims thereby varied, it is possible to adjust the balance for temperature compensation without moving the main balance weights.

387 Marine chronometer

An eight-day chronometer, by George Margetts, made about 1800 and employing an Arnold-type detent escapement. It includes Margetts' device for preventing the endstone from becoming 'pitted' by continual wear. The bottom endstone consists of a rotating agate disc which is mounted on a wheel gearing with the great wheel, the balance pivot

bearing on the disc near its centre. The wear on the endstone is thus distributed round a circle and not confined to one point.
The chronometer is wound from the side.

388 Chronometer

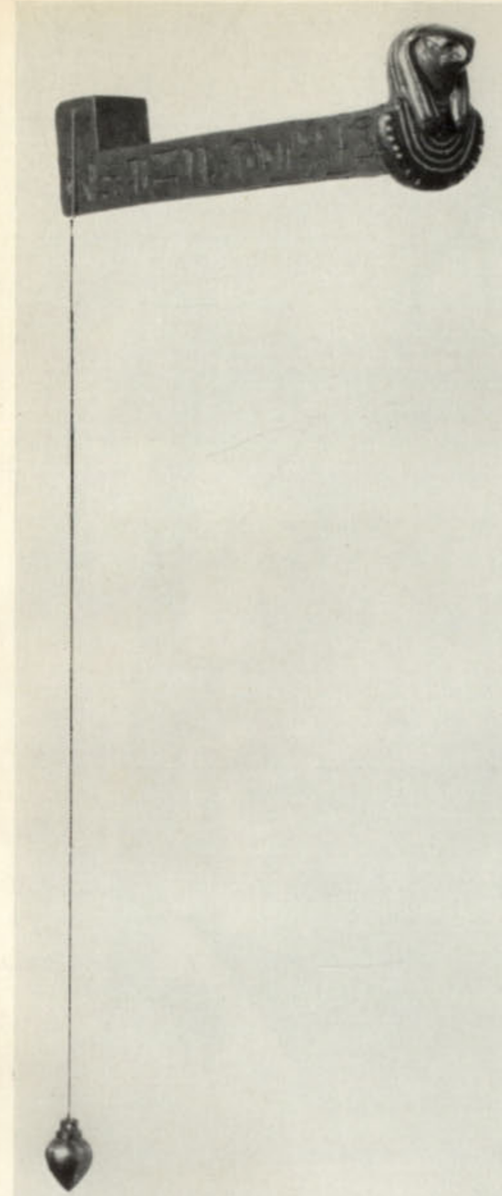
A two-day marine chronometer, made by Lewis Recordon, London, about 1800.
It has an Arnold detent escapement, but instead of the usual arrangement for marine chronometers with which the balance wheel makes 14,400 single vibrations an hour and the wheel train consequently advances every half second, the balance makes 18,000 single vibrations an hour and the train advances five times in two seconds. The roller is entirely a stone, probably a sapphire.
The movement is fitted with a brass cap of the type formerly used for watch movements.

389 Chronometer with Guillaume balance

A chronometer of a type introduced by Paul Ditisheim in 1921 and fitted with a Guillaume balance specially designed to give continuous compensation for variations of temperature. A steel balance-spring is employed, and the balance wheel is of the ordinary cut bi-metallic form, but the steel usually employed in the rim is replaced by a special alloy of nickel and steel due to Dr C. E. Guillaume.
This alloy possesses an expanison co-efficient which varies with temperature, and its properties are such that, combined with brass, it causes the weights of the balance to move inwards more for a rise of temperature than they move outwards for an equal fall, which is the effect desired to compensate exactly for the changing stiffness of the balance-spring. With a balance of this type record results have been obtained in the official trials of watches at the National Physical Laboratory. [See *Proceedings of the Physical Society of London*, vol. 32, pp.374-404.]
The marine chronometer shown includes other special features. It is designed to carry a centre-seconds-hand and is wound by means of a permanently attached button. The hands are set by means of an external push-pin and wheel, and the excapement portion is mounted in a detachable frame which may be removed and replaced by a duplicate when necessary.
The example shown is provided with a lever escapement but an additional interchangeable frame with a detent escapement, elinvar hairspring, and Ditisheim balance is shown separately.
[See *Proceedings of the Physical Society of London*, vol. 35, pp. 261-5, (1923).]

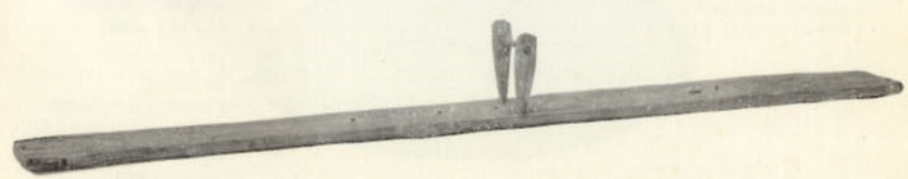
390 Detent escapement with Elinvar hairspring

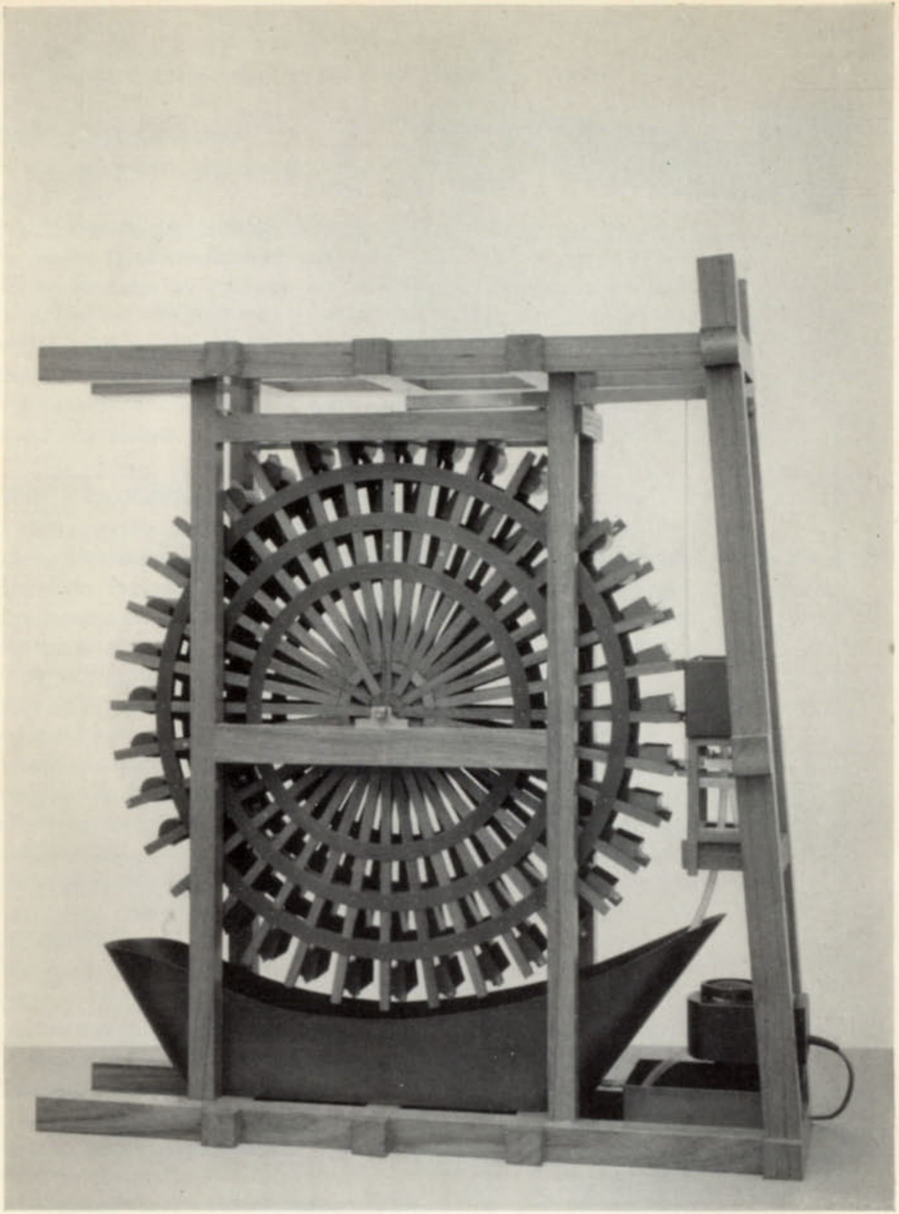
Elinvar is an alloy, introduced about 1920 by Dr C. E. Guillaume in connection with his researches on the properties of nickel-steels. Its modulus of elasticity remains nearly constant over ordinary ranges of



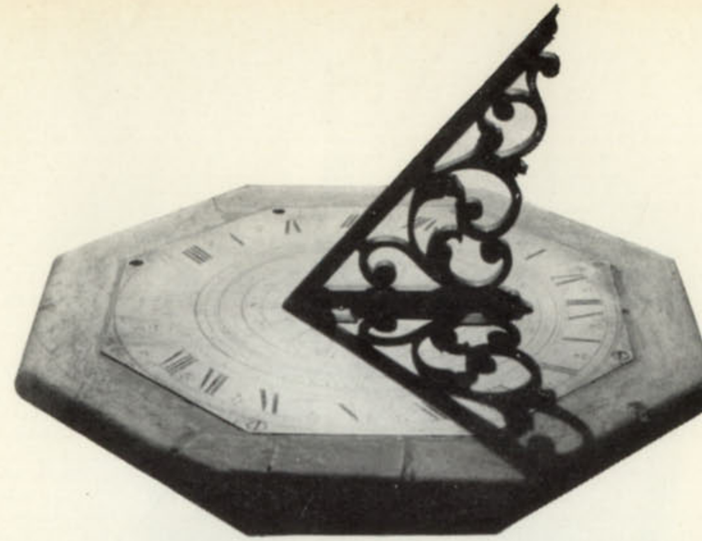
(*left*)
1a Astronomical instrument 'Merkhet' from ancient Egypt (about 600 BC) **(3)**

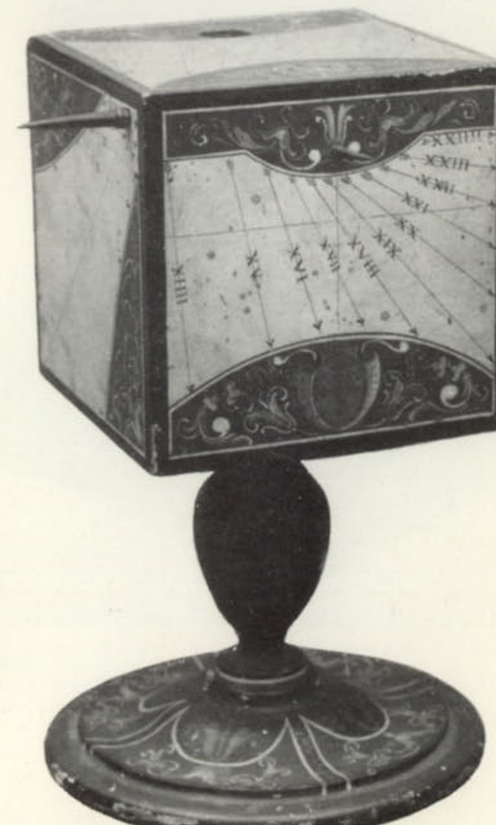
(*below*)
1b Primitive (modern) shadow clock from Egypt **(5)**





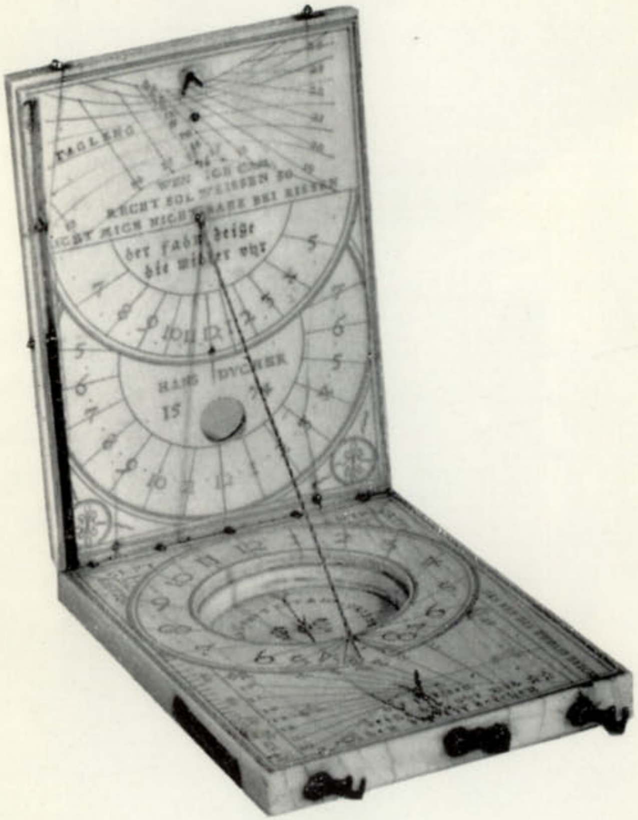
2 Chinese water-balance escapement. (1088) model **(11)**

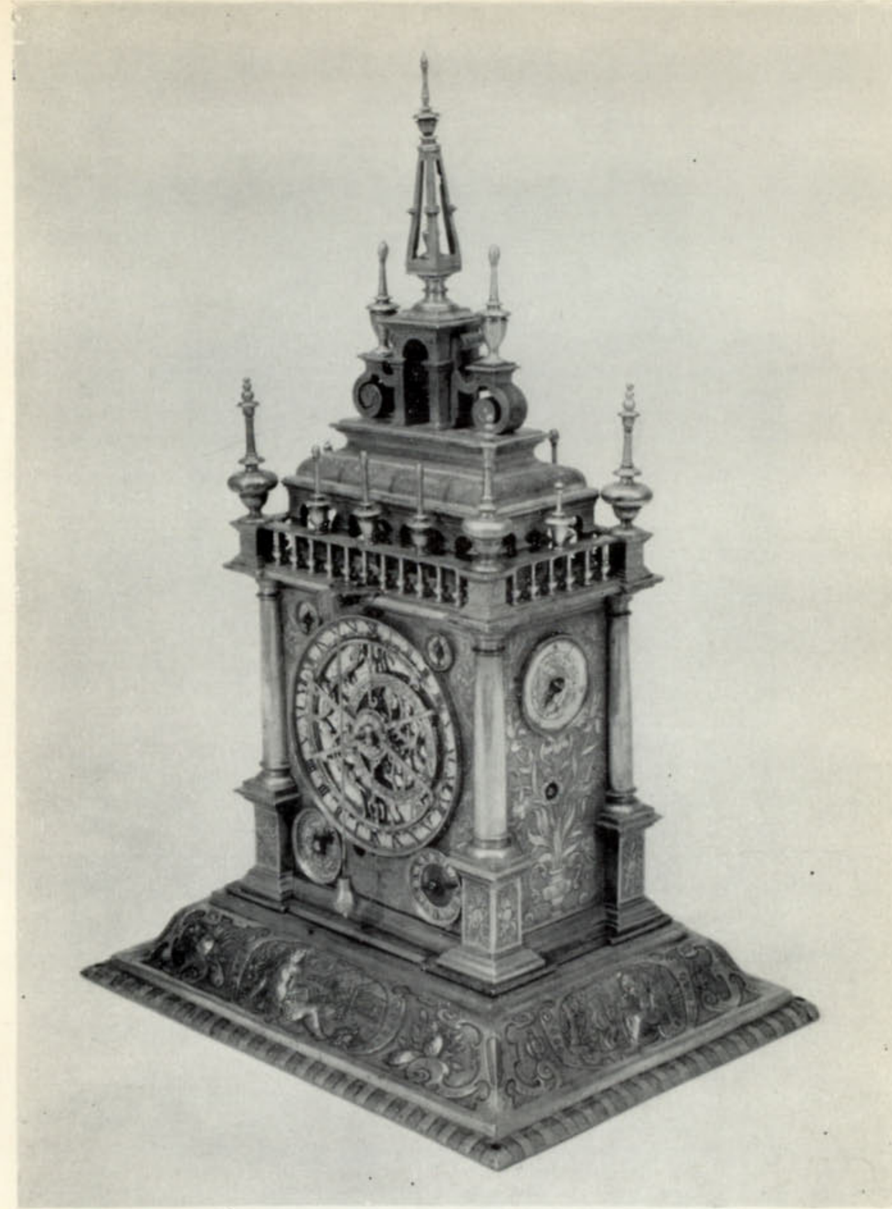




3a *(top)* Garden sundial (1718) **(56)**

3b *(bottom)* Florentine cubical sundial of about 1560, showing Italian hours **(60)**





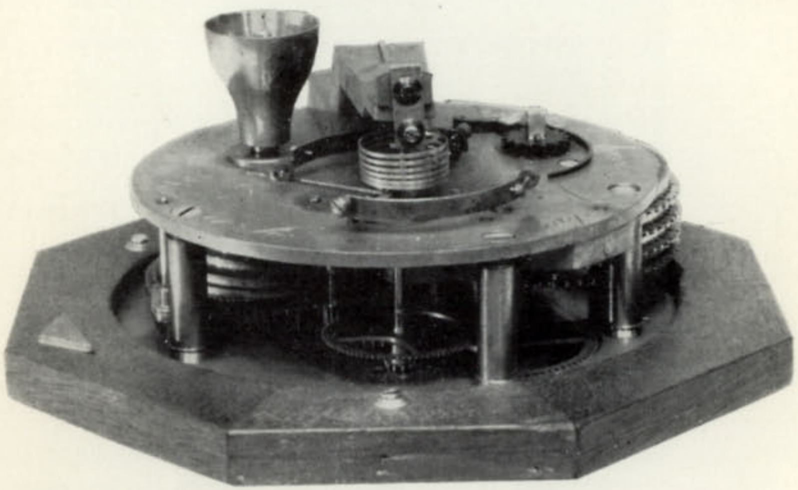
5 Augsburg astrolabe clock (early 17th century) **(187)**

4 *(opposite)* Ivory tablet sundial by Hans Ducher (1574) **(91)**

6 Tompion travelling clock (about 1700) **(191)**

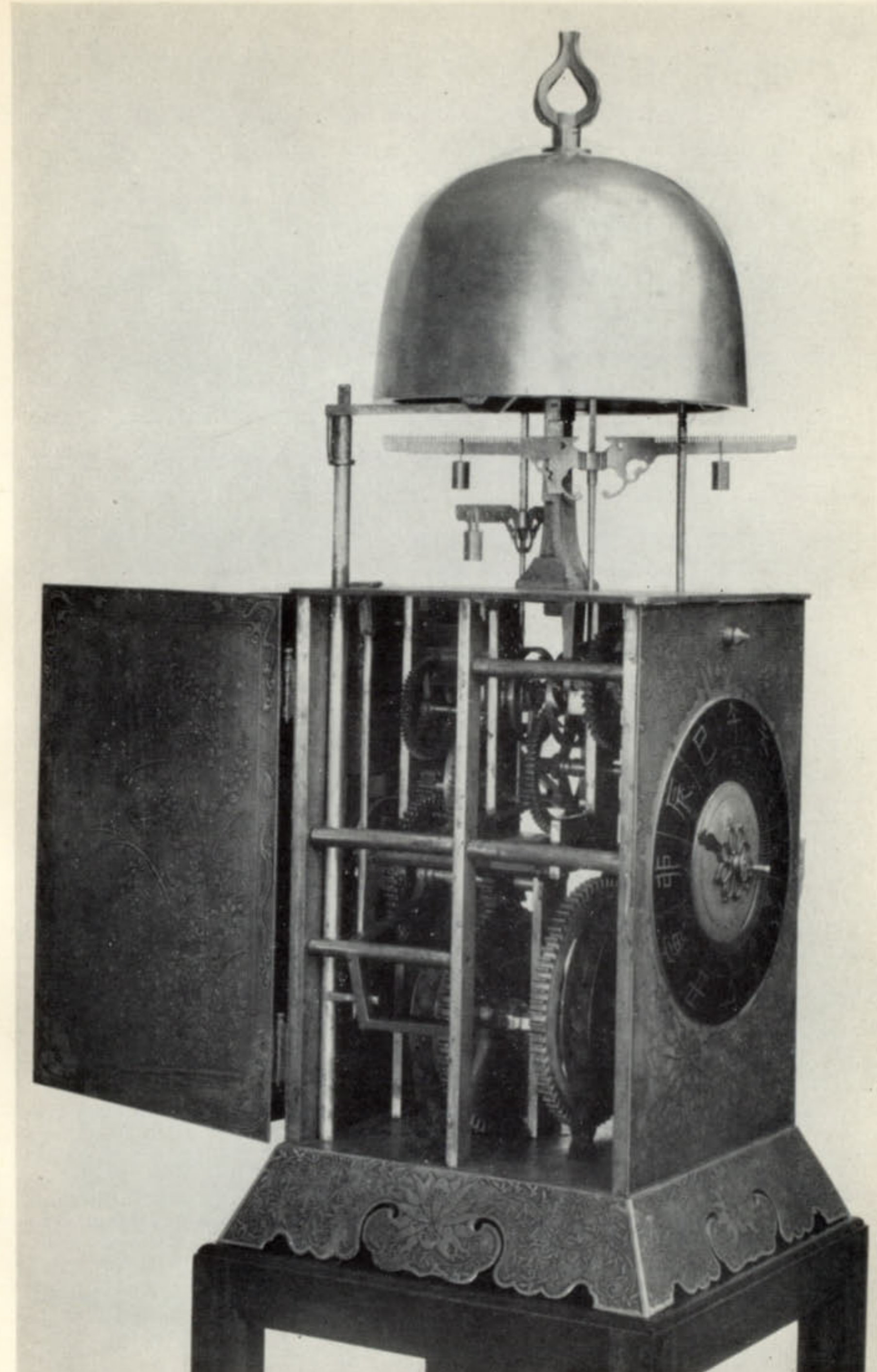
7a *(top)*
Watch with wandering hour figure by William Crayle (about 1660) **(332)**

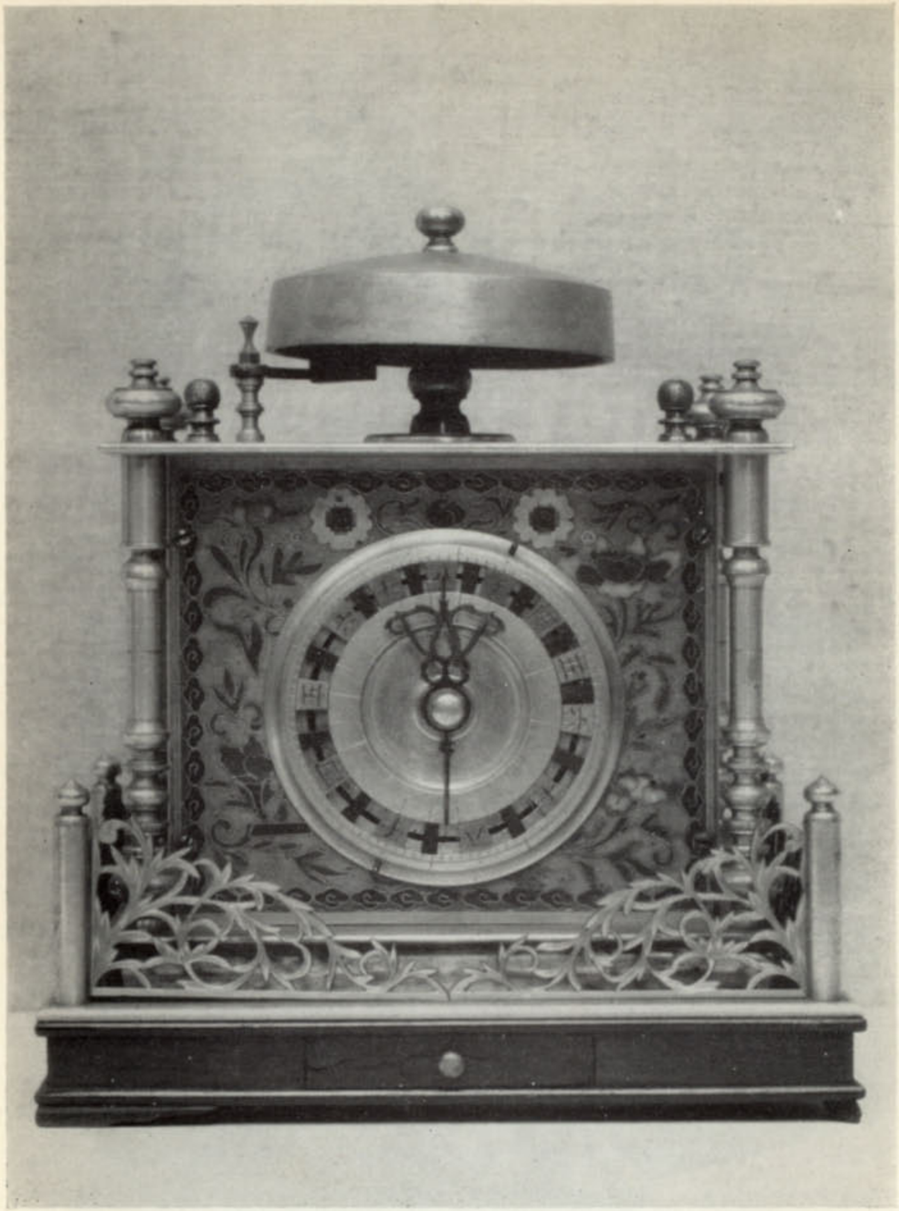
7b *(bottom)*
Verge watch by David Lestourgeon, Rouen (about 1660) **(211)**



8 Marine chronometer by John Arnold and Son (late eighteenth century) **(382)**

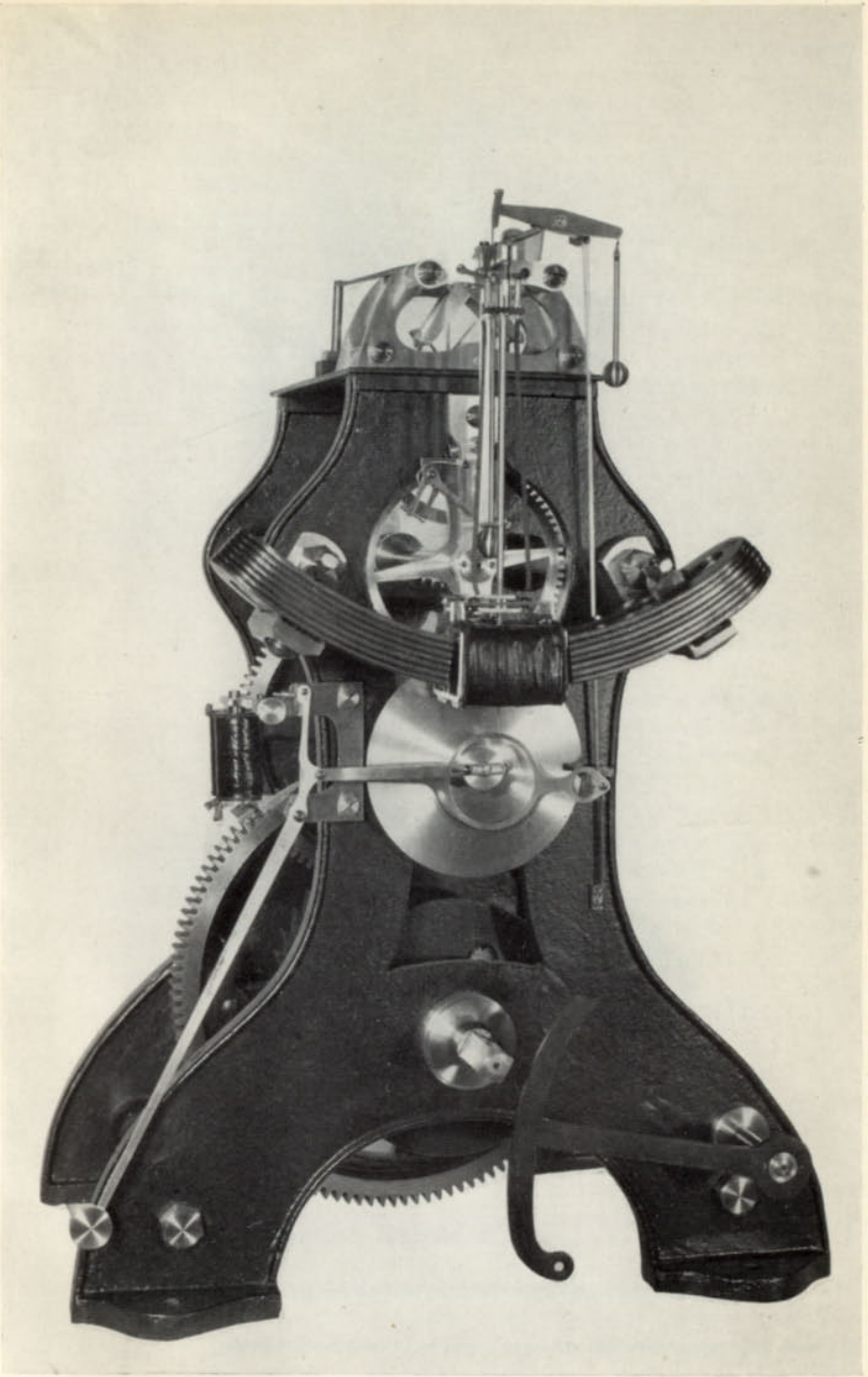
9 Japanese lantern clock with two-balance foliot escapement **(193)**

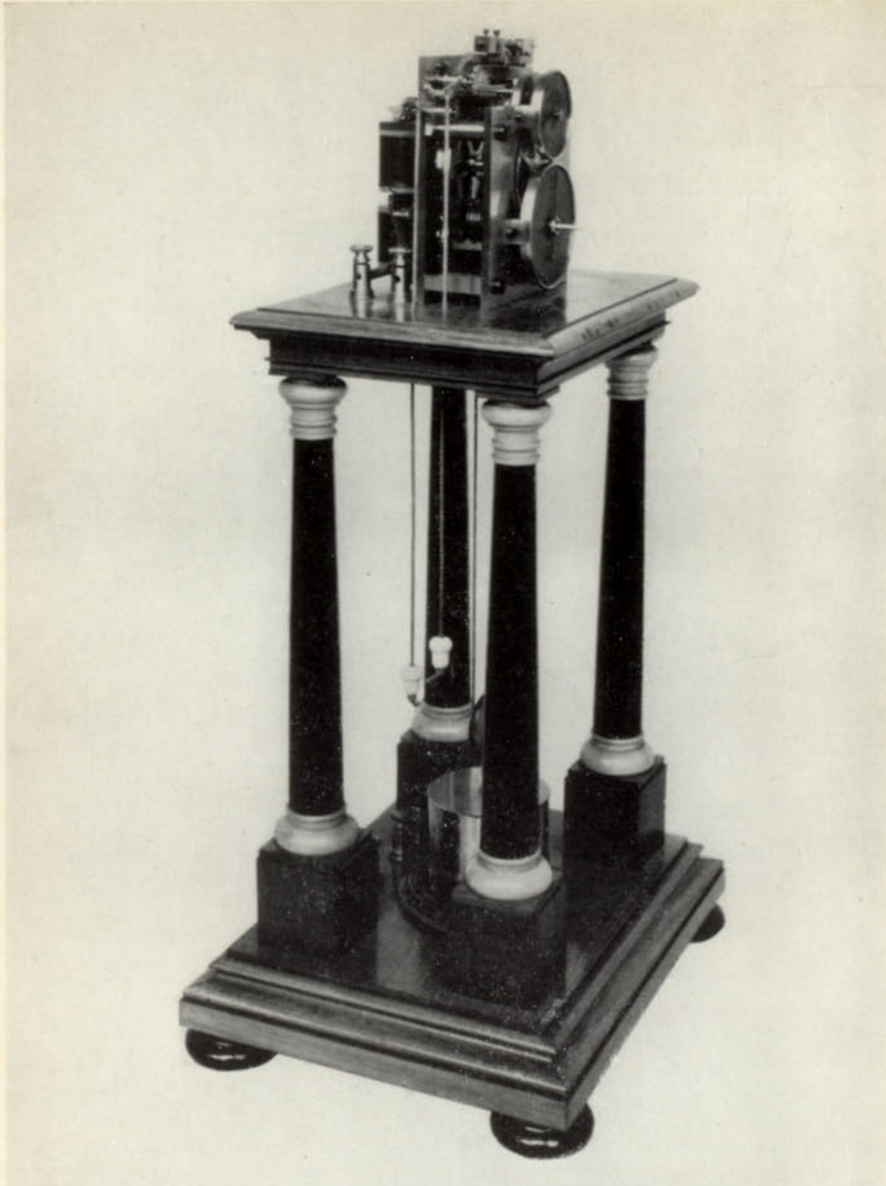




10 Japanese 'bracket' clock **(196)**

11 Wheatstone master-clock (about 1870) **(416)**





12 Hipp chronoscope
(about 1850) **(474)**

temperature and, when employed for the hairspring of a watch or chronometer, it almost dispenses with the necessity of any form of temperature compensation. Such compensation as is necessary can, however, be obtained by adding short bi-metallic blades to an uncut mono-metallic balance, as in the Ditisheim balance employed in this example, made by M. Paul Ditisheim, 1925.

The escapement is mounted in a frame which forms an inter-changeable portion of the adjacent marine chronometer.

Two models on a magnified scale of balances employed with the elinvar hairspring are also shown.

[See *Proceedings of the Physical Society of London*, vol. 35, pp. 261-5. (1923).]

391 Chronometer designed for extreme temperatures

This chronometer, by Thomas Mercer of St Albans, is fitted with a balance-spring made of 'elinvar', an alloy nickel and steel, together with chromium and other elements, introduced about 1920 by Dr C. E. Guillaume. The stiffness of an elinvar spring remains very nearly constant over a wide range of temperatures, and hence the rate of a chronometer employing it is only very slightly affected by temperature changes. The balance wheel of the chronometer exhibited is a solid one, and the small residual temperature effect can be compensated by a short pair of bi-metallic blades.

In 1926 the British Engineering Standards Committee arranged a series of tests of chronometers suitable for use in aircraft. The tests, which were carried out at the National Physical Laboratory, extended over an unusually wide range of temperature from —20°C to +50°C.

The change of rate of this chronometer was found to be small and remarkably consistent over the whole range of temperature, and the report of the test stated that 'if it were found practicable, by further fine adjustment of the bi-metallic affixes, to compensate for the small temperature coefficient, it would appear possible to make the daily rate come within the extremely fine limits, ±1 or 2 seconds, at all temperatures'.

[See *Horological Journal*, vol. 69, pp. 121, 139 and 165 (1927).]

392 Chronometer escapement

This model, by Dent, for use with a projecting lantern, represents the detent chronometer escapement which was invented by Thomas Earnshaw about 1782 and is still generally used in marine chronometers.

Compensation Balances

393 Compensation balances for marine chronometers

1. Balance of modified Earnshaw type. For use with a steel or palladium balance-spring. One pair of bi-metallic arms carries a pair of relatively

heavy fixed weights; the second pair carries two lighter screws whose position can be varied to vary the amount of compensation given.

2. Balance with Poole's auxiliary compensation. A discontinuous compensation for use with a steel balance-spring. Each short fixed arm carries a screw which at normal temperatures just touches the outside of the bi-metallic arms at a point about $\frac{1}{4}$ in. from the fixed end of the latter. At lower temperatures only the arc of the bi-metallic arm beyond this screw can move outwards; at higher temperatures the whole of the arm from its fixed end moves inwards, giving a greater movement of the weight for a given change of temperature.

3. Balance with Kullberg's auxiliary compensation. A discontinuous compensation, for use with a steel spring. Two small extra bi-metallic arms are fitted; these move inwards for a rise of temperature, but cannot move outwards for a fall, as they bear up against the points of a pair of screws carried on the main bi-metallic arms.

4. Balance with Mercer's auxiliary compensation. Similar in principle to (3), a pair of auxiliary arms being fitted which can move inwards from their normal position but are prevented from moving outwards.

5. Guillaume or 'integral' balance. A balance with four equal bi-metallic arms, each made of brass together with Guillaume's special nickel-steel alloy whose expansion co-efficient is greater at low temperatures than at higher ones. Gives very close and continuous compensation for the change of stiffness of a steel balance-spring.

6. Uncut invar balance with bi-metallic affixes. For use with an 'elinvar' balance-spring, whose stiffness is almost independent of temperature. The size of the invar balance is also practically unaffected by temperature changes, and the small residual primary effects are compensated by a short pair of bi-metallic blades which are continuously in action.

7. Uncut brass balance with bi-metallic affixes. Similar to (6), but made of brass instead of invar. Since brass expands a little with rise of temperature slightly more compensation is required, and the compensating weights are slightly heavier than in (6).

8. Balance with sliding bi-metallic affixes. For use with an 'elinvar' balance-spring. The sliding affixes enable the amount of compensation given to be readily adjusted.

[See *The Marine Chronometer* by R. T. Gould.]

394 Loseby's compensation balances

Balances of this form were invented by E. T. Loseby about 1843, and were designed to eliminate the middle temperature error. They were employed in chronometers which occupied high positions in the lists for the Greenwich trials during the period 1845-1852.

In the ordinary form of bi-metallic compensation balance the ends of the rims bend approximately equal amounts inward or outward for equal rises or falls of temperature respectively, but the conditions for continuous compensation require that such outward movement should be less than the corresponding inward movement. Many secondary compensation devices have been employed to eliminate or to reduce this error, the action of some being continuous and that of others discontinuous. Loseby's balance is an example of a continuous compensation.

Superimposed upon a balance of the ordinary bi-metallic form there are two small bulbs with tubes containing mercury as in a thermometer. These are mounted on the free ends of the rims and their tubes are so curved that for a rise of temperature the end of the mercury moves more towards the centre of the balance than it would move away from the centre for an equal fall of temperature, and it is thus possible to arrange for continuous compensation. To prevent the mercury threads breaking, a little air is left in the tubes when they are sealed.

Five modifications are shown. In No. 1 the tube is attached to the weight used for the ordinary compensation, and in No. 2 it is detached. No. 3 is similar to No. 2 with the addition of position screws, and No. 4 is a form in which the tube could be adapted to chronometer balances of the ordinary type. No. 5 is a magnified drawing which illustrates the application to pocket chronometers and watches, and Nos 6 and 7 show tubes in progress of manufacture and finished.

395 Kullberg's flat-rim balance

A balance invented by Victor Kullberg about 1860 and designed to avoid the middle temperature error, which is present in the ordinary form of bi-metallic compensation balance. Chronometers with this balance headed the lists in the trials at the Royal Observatory, Greenwich, in 1864, 1872 and 1873.

The arm and the rims are flat and made up of brass and steel. In the arm the brass is at the top, but in the rims it is at the bottom. A rise of temperature causes the ends of the arm to bend downwards and the free ends of the rims to bend upwards and in so doing to move slightly inwards. The balance weights are mounted on short pillars above the rim and consequently the amount by which they move inward for a certain rise of temperature is greater than the amount they would move outward for an equal fall in temperature, a condition which is necessary to secure continuous compensation.

396 Ditisheim compensation balances

(Scale about 4 : 1.)

These models represent a type of compensation balance designed about 1923 by Paul Ditisheim for use with elinvar hairsprings. Each consists of an uncut mono-metallic ring with the addition of short bi-metallic blades to effect the small amount of temperature compensation required.

In order to reduce the air friction and lessen the variations in time keeping which follow changes in the atmospheric pressure the compensating blades are placed in recesses in the rim of the balance.

An advantage of the uncut balance is the absence of changes of shape arising from centrifugal forces, the differences between which in long

and short arcs of vibration lead to complication in the adjustment of the hairspring.

[See *Proceedings of the Physical Society of London*, vol. 35, pp. 261-5 (1923).]

397 A ship's chronometer in use

The left-hand photograph shows the navigating officer of SS *Chitral* of the P & O-Orient Lines checking one of his ship's chronometers by means of a radio time-signal.

The photograph on the right shows the *Chitral* herself at sea, under open-sea conditions in which she is being navigated without direct visual aids.

398 Chronosphere

This consists of a terrestrial globe which is driven by a clock mechanism contained in the base and makes one complete rotation from west to east in 24 hours. With its aid the local mean solar time at any place on the earth's surface can be determined by following a line of longitude from the place in question to the equator and reading off the time upon the hour ring which surrounds the equator.

The globe is mounted upon an axis inclined at $23\frac{1}{2}°$ to the vertical and the sun would therefore lie always in a horizontal plane passing through the centre of the globe.

399 The Willis 'World Clock'

A clock specially designed to show the time at any place in the world, and intended for use by cable companies, radio operators, news agencies, persons receiving wireless programmes from far distant stations, or in any other connection in which it is necessary to know the time in distant countries.

The dial carrying the hour marks rotates anti-clockwise in the centre of the fixed dial. The fixed dial bears 24 principal radial lines corresponding to the 24 standard time-zones into which the world is divided, and on each of these lines are inscribed in black letters the names of the principal countries belonging to that zone.

The time in each particular zone is read off from the point at which its radial line meets the rotating hour circle. For greater accuracy in reading the minutes a single hand, rotating once an hour, is mounted below and shows the number of minutes past the standard hour everywhere, the red or reverse end of the hand showing the number of minutes past the hour for the few countries such as India whose time-zone lies half-way between two of the standard zones. A few countries have a standard time differing by a fraction of an hour from standard zone time, and in these cases the small figure adjoining the name shows the number of minutes to be added to or subtracted from the reading of the minute hand.

400 Chart showing standard time around the world

The difference between one time-zone and the next is normally one hour, and over the open oceans and large land areas of the same country the zone boundaries usually run along lines of longitude at intervals of 15°; but in many land areas and over island-studded seas they follow national frontiers.

A few zones differing by half-hours from the standard zones are shown in purple, and a few other non-standard zones in yellow or grey.

8 Escapement models

401 Recoil escapement

This model shows the anchor or recoil escapement which was invented by William Clement or Robert Hooke about 1670.

The escape wheel teeth engage alternately with two inclined faces or pallets, which form part of an anchor-shaped piece, and during such engagement a tooth tends to move a pallet sideways until the tooth escapes past the edge of the pallet face. The wheel then turns a little until stopped by the engagement of another tooth with the opposite pallet, and as the anchor continues to move under the action of the pendulum the wheel is made to recoil until the pendulum comes to rest.

This form of escapement is the one which is most extensively employed for clocks, other than precision clocks.

The model is so designed that the actions can be projected on a screen.

402 Dead beat escapement

This model shows the dead beat escapement which was invented by George Graham about 1715.

In this escapement the locking faces of the pallets form parts of circles with the pallet staff as centre, and the escape wheel consequently remains at rest except when engaging with the inclined impulse faces of the pallets. This form of escapement is the one which has been most generally used for weight driven clocks of precision.

The model is so designed that the action can be projected on a screen.

403 Cylinder escapement

The horizontal cylinder escapement was invented by George Graham about 1720, and may be regarded as an improvement of an escapement invented by Booth, Houghton and Tompion in 1695. It has a 'dead-beat' action similar to that of Graham's dead-beat escapement for clocks.

The model represents the action on a magnified scale.

The escape wheel teeth are pointed and engage with an incomplete hollow cylinder which is mounted on the same axis as the balance wheel. Locking of the escape wheel is effected alternately on the outer and inner surfaces of the cylinder which are highly polished, and the impulses are given by the action of the inclined faces of the teeth upon the edges of the cylinder. As the balance may swing through a large angle, it is not possible to have the teeth in the same plane as the body of the wheel, and the teeth are consequently mounted on the ends of vertical arms.

This escapement was formerly very extensively employed, more especially in Swiss and French watches.

404 Clock with rack-lever escapement

This escapement was patented by Peter Litherland of Liverpool in 1792, but a very similar one had been invented in 1722 by the Abbé d'Hautefeuille. It differs from Mudge's detached lever escapement in that the lever, instead of delivering an impulse to the balance once per swing, carries a rack which engages continuously with a pinion mounted on the balance staff.

It is not, therefore, a detached escapement.

405 Lever escapement

This model represents, on a magnified scale, the detached lever escapement which, in various modified forms, is now almost universally employed for pocket watches. It was invented by Thomas Mudge about 1755, but was not used to any great extent until a much later date.

An escape wheel of 15 teeth engages with two pallets which are mounted on a lever. One end of this lever is notched to engage with a pin carried by a disc or 'roller' on the balance axis, and the motion of the lever is limited by two pins, known as 'banking' pins.

A pin, known as the 'safety' pin, which is mounted on the lever near to the notch, prevents the lever from moving except when engaged by the roller pin.

In Mudge's original form the locking faces of the pallets were circular, as in the dead-beat escapement for clocks, but in the later forms, with which success was obtained, the locking faces are straight, and are so inclined that an escape wheel tooth, pushing against a locking face, tends to 'draw' it towards the wheel and, by so keeping the lever against a banking pin, prevents the safety pin from continually touching the roller. This supplementary invention of 'draw', which rendered the escapement practicable, appears to have been due to Josiah Emery.

This form of escapement is known as 'detached' because the balance is free from any engagement during the greater portion of its swing.

406 Model of Swiss lever escapement

(Scale 10 : 1.)

In this form of the lever escapement, also known as the club-tooth lever escapement, the tips of the escape wheel teeth take the form of inclined planes and the impulse is obtained in two stages, first by the engagement of the planes of the teeth with an edge of the pallet and next by the engagement of the edge of a tooth with the impulse plane of a pallet.

The club-tooth has the advantage of retaining oil better than a pointed tooth, of requiring less 'drop' (as the free motion of the wheel between engagements with the pallets is termed) and also of being less fragile and its employment in watches has increased considerably during the present century.

In this escapement it is usual to mount the balance staff, the pallet staff and the escape wheel staff all in the same straight line, and with this layout the excapement is sometimes referred to as the 'straight line escapement'.

An additional interesting feature of the present model is that the balance-spring is of the 'overcoil' shape invented by Breguet about 1800 which gives better isochronism between large and small arcs of swing than the more usual flat spiral employed in watches.

407 Model of chronometer escapement

Shows, on a magnified scale, the form of detent escapement invented by Thomas Earnshaw about 1782, which still remains the standard form for use in marine chronometers.

The escape wheel teeth are locked by a locking pallet carried on a bar or detent which is mounted on the end of a strip spring. Attached to the detent on the side nearer the escape wheel there is a fine strip spring which slightly projects beyond the end of the detent. Rollers or discs on the balance carry an unlocking pallet and an impulse pallet. The former engages with the fine spring and when moving in one direction encounters little resistance as the spring bends along its full length and is easily pushed away. On the return motion, however, the fine spring is pushed against the detent and the short portion of this spring which projects beyond the end is stiff enough to cause the detent to be moved by the action of the unlocking pallet. This motion is sufficient to release the escape wheel and, as the latter advances, one of its teeth engages with the impulse pallet and gives an impulse to the balance, such impulse being given on alternate vibrations only.

For demonstration purposes the model is fitted with graduated scales whereby the angles over which the various operations take place can be read and, in addition, provision is made for showing the effects of altering the distances between the various elements of the mechanism.

408 Model of the escapement employed in the early 'Waterbury' watches

Shows, on a large scale, the escapement which was employed in the Waterbury watch, which was first put on the market in the USA in 1880, and was one of the first watches to be sold at a price which made it available for the multitude.

The escapement is a modification of the so-called 'duplex' type, which was invented during the second half of the eighteenth century. In this mechanism the escape wheel is provided with two sets of teeth, one set for impulsing and one for locking.

An impulse is given to the balance at alternate vibrations and in addition to the main impulse the balance receives a subsidiary small impulse from each long tooth as it engages with the notch. The two impulses are known as the 'great lift' and the 'small lift' respectively.

An example of a Waterbury watch of about 1885 is exhibited adjacently.

409 Eight-day pendulum clock with magnetic escapement

The clock here exhibited represents one form of the magnetic escapement for pendulum clocks invented by C. F. Clifford and patented by him in 1947. In this escapement there is no actual mechanical contact

between the escape wheel and the pendulum, the impulse to the pendulum being transmitted by magnetic forces. Friction between the escape wheel and pallets is thus eliminated, and although there are hysteresis and eddy-current losses in the magnetic elements these are so much less than the frictional losses in an anchor or dead-beat escapement that the mechanical efficiency is increased by a factor of approximately three, so that a given spring will drive a clock three times as long if the gearing is re-arranged accordingly. The clock is almost completely silent and the escapement of course requires no oil.

In the example shown, the magnet is of 15 per cent cobalt steel and takes the form of a figure-of-eight, the poles facing each other at the waist; the escape wheel is of Mu-metal. The magnetic circuit remains almost closed throughout the period of the pendulum's oscillation. The escape wheel is so shaped that an approximately sinusoidal impulse is given to the pendulum, with a maximum at the centre of the swing in each direction. As with a mechanical escapement, the escape wheel moves through the pitch of one tooth for each double swing of the pendulum.

Two guard pallets are provided; these normally move clear of the star-wheel, but one or other will engage with it and prevent the wheel train from 'running away' in the event of the magnet poles moving too far away from the escape wheel to control it, e.g., if the clock is lifted and tilted.

Examples of the magnet and star-wheel can be seen mounted on a board adjacently.

[See British Patent Specification No. 596,216.]

410 Eight-day timepiece movement with magnetic escapement

A movement similar in principle to the adjacent one, and representing a different form of the magnetic escapement invented and patented by C. F. Clifford in 1947.

The permanent magnet mounted on the pendulum is in the form of a circle with two small internally projecting pole-pieces, while the escape wheel is in the form of a crinkled sine-wave. As in the adjacent example, the magnetic circuit remains almost closed throughout the period of the pendulum's oscillation, and the escape wheel is so shaped that an approximately sinusoidal impulse is given to the pendulum, with a maximum at the centre of the swing in each direction. As with a mechanical escapement, the escape wheel moves through the pitch of one tooth for each double swing of the pendulum.

Two guard pallets are provided to prevent the escape wheel from running freely if the clock is tilted through a large angle.

Made by Rotherham & Sons, Ltd.

[See British Patent Specification No. 596,216; also *Mond Nickel Bulletin*, vol. 21, p. 138 (1948).]

411 Alarm clocks with magnetic escapement

These clocks have no pendulum or balance-wheel, the timekeeping element being a vibrating reed to which a thin horseshoe magnet is

attached. The teeth of the escape wheel, which is made of Mu-metal, pass between the poles of the magnet, and the wheel, driven in the usual way from the mainspring through a reduction gearing, is permitted to move through the space of one tooth for each complete up-and-down vibration of the magnet.

A safety catch attached to the magnet prevents the wheel from 'running away' if synchronism is lost, but neither this nor the magnet itself normally touches the escape wheel, the control being wholly magnetic.

Regulation is effected by means of a screw of magnetic material, which can be moved towards or away from the vibrating magnet, and increases the magnet's frequency slightly when nearer to it.

The clock is in quantity production by a German clockmaking firm.

412 Set of eight models of clock escapements

(a) Early type of verge escapement.
(b) Tic-tac escapement.
(c) Anchor escapement for long-case clocks.
(d) Late verge escapement for bracket clocks.
(e) Anchor escapement for bracket clocks.
(f) Graham's dead-beat escapement.
(g) Half dead-beat escapement.
(h) Dead-beat regulator escapement.

413 Movement of clock with 'floating balance' escapement

A modern escapement for domestic clocks, intended to replace a short pendulum, and less sensitive to level than a pendulum.

The balance is suspended by its own helical balance-spring, which is wound in two halves in opposite directions to prevent rise and fall of the balance as it swings.

Regulation is by means of a pair of weights pressed against the inner surface of the balance rim, which is not quite circular in shape.

The escapement itself is of a conventional pin-pallet type, but the pallet fork is bent over at right-angles to engage with the impulse pins on the balance.

[See *Horological Journal*, vol. 98, p. 163 (March, 1956).]

9 Electric clocks and watches

Ever since the discovery early in the nineteenth century of the magnetic effects of electric currents inventors have tried various ways in which electricity can be used in the measurement of time. Electric currents have been employed chiefly for two purposes—to supply the power necessary to drive a clock, and to transmit synchronising signals from one 'master' clock to a number of distant clocks, so that all may indicate the same time.

Electrically driven independent clocks can be divided into three main classes:

(1) Clocks in which the pendulum is kept swinging by forces due to electro-magnets.

(2) Clocks in which the impulse to the pendulum is given by the fall of a gravity arm or the release of a spring which is afterwards restored to its original position by an electro-magnet—these may be termed 'electric gravity escapements'.

(3) Mechanical clocks in which the driving weight or spring is re-wound at intervals by some form of electric motor.

Various methods of distant control have been used. In the earliest ones, currents were sent out from a master clock every second, so that the pendulums of the subsidiary clocks were kept swinging in unison with that of the master clock. This method has now been superseded by others in which the currents are sent out less frequently.

In a system which has been widely used, the master clock sends out a current every minute or half minute which energises the electro-magnet of each distant 'impulse dial' and so moves its hands through the space of one minute or half a minute. In other systems the subsidiary clocks are independent spring-driven clocks whose hands are automatically set right every hour by a current impulse transmitted from the master clock. In a still further system each subsidiary clock is driven by a synchronous electric motor operated from alternating current the frequency of which is kept constant.

Electric watches first came on the market in 1957. In the majority of them the balance wheel makes an electric contact and receives an electro-magnetic impulse every swing or half-swing, but in the 'Accutron' the balance wheel is replaced by a vibrating tuning-fork.

414 Bain electric clock

Alexander Bain was one of the pioneers of electric clocks, and his patents extended over the years of 1845-7; the clock exhibited is an early example of his work.

The circular pendulum bob is magnetised, and at each end of a swing it enters one or other of two coils mounted on the clock case.

An electric contact is made every double swing by means of a metal slider which runs in two grooves in discs one of which is partly of metal and partly of insulator. When the contact is made a magnetic impulse is given to the pendulum, making good the losses of energy due to friction.

The clock hands are moved forward by a simple ratchet wheel and pawl mechanism, the pawl being attached to the pendulum near its top.

415 Wheatstone impulse dial

In 1840 Wheatstone published a paper in the *Proceedings of the Royal Society* entitled 'Description of the Electro-magnetic Clock' in which he gave an account of various ways in which an electric master clock could be made to send electrical signals and so propel a series of distant repeaters or 'impulse dials'.

The dial here exhibited corresponds to one of those described in this paper, and is to be driven by impulses of current arriving once per second.

When such a current impulse passes through the electro-magnet of the dial, its armature is attracted, against the pressure of a spring, and afterwards released. The two pallets attached to the sliding armature engage with the opposite sides of a double-sided crown-wheel, and a single to-and-fro motion advances this wheel through the pitch of one tooth. The seconds-hand of the dial is co-axial with this crown wheel, and so is correspondingly advanced through the space of one second. The minute and hour-hands are driven from the seconds-hand by suitable reduction gearing.

[See *Royal Society's Proceedings*, A, vol. 4, p. 249 (1840).]

416 Wheatstone master-clock

(*See Plate 11*)

An example of the type of master clock which was being constructed by Wheatstone's company, the British Telegraph Manufacturing Company, about 1870.

The pendulum of a powerful mechanical clock carries a coil which swings over a pair of horseshoe magnets. The movement of the coil in the magnetic field generates a current which is transmitted to the dial movements in circuit with the coil. The pendulum thus behaves as a dynamo generating alternating current at a frequency of one cycle per second, and the dial movements are effectively synchronous motors driven by this current. The system, although it eliminates troubles due to faulty contacts, is bad from the timekeeping point of view, since the interference with the free motion of the pendulum is very great.

Accordingly, the master clock is provided with a synchronising mechanism, of a type patented by J. M. A. Stroh, in which it receives a synchronising signal from an accurate clock every two hours. If it is slow, the subsidiary pendulum linked with the main one is effectively shortened, so that the pendulums will be speeded up; if fast, the pendulums are correspondingly slowed during the ensuing period.

[See British Patent Specification No. 3028 of 1869.]

417 Wheatstone impulse dial

Designed for use with the adjacent master clock, which sends out pulses of current, generated from the swinging pendulum, twice per second, in alternate directions.

The movement of the dial consists of three flat magnets mounted on the same axis of rotation, one magnet lying within a coil carrying the current while the others lie outside it. The magnets are arranged so that the north-seeking pole of one lies above the south-seeking pole of the other, so that there is no resultant force on them from the earth's magnetic field, while the field from the coil urges them in the same direction: the magnet system is, in fact, astatic. In operation the magnets make one rotation per second about their vertical axis, and so drive the minute and hour-hands of the impulse dial through suitable reduction gearing.

Each dial movements is, in fact, an electric synchronous motor, operating from the alternating current at one cycle per second generated by the pendulum of the master clock.

418 Electrically controlled clock

This clock illustrates a method of synchronisation introduced in 1858 by R. L. Jones, in which the pendulums of a number of ordinary weight-driven mechanical clocks are made to swing in unison with that of a 'master' clock by means of electro-magnetic impulses due to electric currents sent out every second from the master clock. With this, which was one of the first systems of distant control of a number of clocks to be introduced in this country, the individual clocks still continue to go even if the electrical circuit is accidently broken, though they are then no longer synchronised.

The pendulum of the subsidiary clock carries a coil which swings over a system of two magnets with their north poles facing, as in the adjacent Bain clock. Currents from the master clock, which is of the Bain type, pass through these coils every second; if the pendulum is late the forces on the coil tend to accelerate it, if early to retard it, so that it is kept synchronous with that of the master clock.

The example exhibited was made about 1880 for the General Post Office.

[See British Patent Specification No. 702 of 1857.]

Electrically Maintained Pendulums and Balance-Wheels

419 Féry's electrically driven pendulum

In this device, invented and patented by Professor Charles Féry of

Paris in 1907, a pendulum receives impulses from an electro-magnet every swing, but the contact-making is done by a subsidiary pendulum driven from the main pendulum by electro-magnetic attraction. The main pendulum is thus free in so far as it makes no material contacts, but the interference with its motion due to contact-making, though indirect, is still very considerable.
The bob on the main pendulum consists of a horseshoe magnet, one pole of which threads a fixed coil, while the other passes through a copper ring carried on the subsidiary pendulum. Eddy currents are set up in the copper ring, and the forces between these and the magnet of the main pendulum tend to reduce relative motion, so that the subsidiary pendulum is kept swinging. The left-hand contact makes the circuit through the fixed coil which gives the impulse to the main pendulum, while the right-hand contact can be used to drive or control a subsidiary clock or system of dials.
The coil is made of high resistance in order to reduce the relative importance of variations of contact resistance.
[See British Patent Specification No. 23,146 of 1907.]

420 Bulle electric clock

An electrically driven clock invented by Professor Marcel Moulin and M. Favre-Bulle about 1920.
The pendulum carries a solenoid moving over a curved bar magnet with consequent poles, north-seeking in the middle and south poles at the ends. A current from a cell passes through the coil during part of alternate swings, and the interaction between this current and the magnet supplies the impulse necessary to maintain the pendulum in vibration.
A pin near the top of the pendulum engages with a forked lever and completes the electric circuit, one side of the fork consisting of conducting metal and the other insulating fibre. By means of a pawl the forked lever propels a crown ratchet wheel which is connected with the hands by worm gearing.
The motion of the coil in the magnetic field generates an electromotive force in opposition to that of the cell and consequently the larger the arc of vibration and the quicker the motion of the coil at the middle of its swing, the smaller the current passing from the driving cell.
For the purposes of eliminating the circular error of the pendulum and controlling the arc of vibration, one end of a short helical spring is attached to the pendulum rod, the other end of the spring being fixed on the centre line below the pendulum suspension.

421 Electrically driven clock

A clock, by M. Hipp, Neuchâtel, fitted with the 'butterfly escapement which was invented by Matthaüs Hipp in 1842. With this escapement an electrical contact is made when the arc of vibration of the pendulum falls below a certain amount, and an impulse is consequently given to the pendulum.
The pendulum carries an armature and swings above an electro-magnet, while pivoted to the bottom of the pendulum there is a small trailer which slides over a small notched block. When the vibrations are large enough the trailer moves clear of the block at each swing, but when the vibrations fall below a certain amount the trailer does not leave the block and engages with a notch as the pendulum returns. This causes a spring on which the block is mounted to be depressed and thus closes the circuit through the electro-magnet, which then attracts the armature fixed to the bottom of the pendulum and so imparts the necessary impulse to the pendulum.

422 'Eureka' electrically driven clock

A clock, invented in 1906 by T. B. Powers and Messrs. G. and H. Kutnow, and made by The Eureka Clock Company, Ltd., which differs from most other electric clocks in that it is controlled by a balance-wheel instead of by a pendulum, but resembles other types in principle in that the oscillating system—in this case the balance-wheel—makes a contact and receives an impulse from an electro-magnet near the middle of its swing. In this clock, as in others, variations of battery voltage affect the magnitude of the impulse and hence the arc of swing, and the force required to make contact is supplied by the balance-wheel.
The balance wheel carries an electro-magnet which, when energised, is attracted to an armature fixed in the base of the clock. A pin on the balance wheel makes contact near the middle of the balance swing with a blade: the electro-magnet is then energised and an impulse given to the wheel.
In the clock exhibited the contact blade has been renewed.
[See British Patent Specification No. 14,614 of 1906.]

423 'Sectronic' battery-powered timepiece

The movement of a modern timepiece in which the balance receives electro-magnetic impulses as in an electric watch.
A coil is mounted on the balance, and this passes between the pole-pieces of a fixed magnet. The coil is in two parts: a driving and a triggering coil; and the three leads to it are taken in through the three hair-springs. The triggering coil is connected to the base side of a transistor, which allows current to pass through the collector side and the driving coil at the correct moment for impulse.
[See *Horological Journal*, vol. 105, p. 47 (February, 1963).]

424 'Clinker' mains-driven non-synchronous electric clock

In this clock, invented by R. C. Clinker of the B.T.H. Co. in 1932, impulses to the pendulum are given every swing by means of an electro-magnet excited from the AC mains supply. The electro-magnet is 'tuned' to the frequency of the supply by means of a parallel capacitor, and both are fed from the mains through a small series capacitor.

As the pendulum approaches its central position, its iron armature approaches the fixed electro-magnet, altering its effective inductance, and throwing its circuit out of tune. The current in the circuit is therefore reduced and the pull on the armature decreased accordingly. It can be shown by fairly simple electrical theory that both these effects have a small time-lag, so that the pull on the pendulum is slightly less as it moves away from its central position than on its approach to that position on its downward swing.

The pendulum therefore receives a net impulse every swing.

The pendulum operates the clock dial mechanism through a one-sided crutch and a simple pawl-and-ratchet mechanism.

For proper operation, the pendulum requires a fairly large arc of swing, and the clock cannot be considered one of high precision, but its accuracy is sufficient for normal domestic purposes.

The power consumption is extremely small.

[See *Institution of Electrical Engineers, Students' Quarterly Journal*, vol. 4, No. 16, p. 163 (June, 1934).]

Electric Gravity or Constant-Force Escapements

425 Froment's electrically driven pendulum

A method of maintaining a pendulum invented by Froment in 1854. During part of a swing to the left an arm attached to the pendulum pushes against a spring, while for a rather longer portion of the return swing the spring pushes the arm, a balance of energy being thus available to keep the pendulum in motion. The impulse is imparted near the end of a swing, but its magnitude is independent of the voltage of the battery, and the force which drives the pendulum also presses the contacts together, thus making a reliable contact.

This arrangement is similar to a gravity escapement in that the impulse is constant and independent of the driving force.

426 Electrically maintained free balance

In this escapement, originally patented by Mr. Sydney J. Smith in 1931-2, the balance-wheel oscillates under the influence of a helical balance-spring. One end of the spring is attached to the balance and the other end is pinned to a pivoted arm. The oscillations of the balance are maintained by the movements of this arm, which alter the effective pull of the balance-spring.

Energy is transferred from a flat spring to the wheel, and eventually to the balance through the balance-spring, at every swing. It will be noticed that the balance-wheel has no 'unlocking' duty to perform, and that it receives its impulse through the medium of the balance-spring.

The counting mechansim is of the type invented by Mr. S. J. Smith for the 'Princeps' master-clock, which can be seen in an adjacent impulse dial movement. The motion of each backstop click breaks the electrical circuit, so that the current pulses required are brief.

[See *British Patent Specifications Nos.* 362,518 *and* 370,956.]

427 Free pendulum clock maintained by rolling balls

In this clock, invented and made by Captain E. E. Craig, the pendulum receives its impulses from a pair of light steel balls which roll down two short ramps attached to the pendulum by horizontal arms. It is termed a 'free pendlum clock' because the pendulum has no 'unlocking' duty to perform, and swings freely except while it is actually receiving its impulse, and for the small fraction of a second during which the ball rests against the edge of the ramp before rolling down it.

The cycle of operations during a complete double swing of the pendulum is as follows: after the right-hand ball has imparted its impulse to the pendulum, it rolls away towards the back of the clock movement and operates a trigger which allows the right-hand mercury switch to tilt over and close its circuit. The right-hand electro-magnet operates, and the resulting movement throws the right-hand ball upwards to its highest position, and at the same time releases the small catch holding the left-hand ball. This ball then rolls a small fraction of an inch until it rests against the edge of the left-hand pendulum ramp, which is then on its downward travel.

As the ramp descends, the ball is able to roll down it, impart its impulse, and then roll away towards the back of the clock movement.

The second half of the cycle is similar, but with 'right' and 'left' reversed.

The rocking movement of the lever driven by the two electro-magnets is converted to a rotary movement which drives the hands of the clock.

428 Parriss rolling-ball clock

A 'free-pendlum' clock which resembles the Craig clock near by in that the 'slave' consists of a rolling ball. In the Parriss clock, however, the ball does not deliver the impulse direct to the pendulum, but through the medium of a gravity arm, upon which it rests. The ball takes a small fraction under two seconds to complete its travel circuit.

The pendulum swings freely apart from the short interval of time during which the pallet on the gravity arm rests on the small wheel mounted on an arm projecting from the pendulum, and the actual time of the impulse as this pallet falls away from the wheel.

The Parriss free pendulum clock is thus a much simplified version of the Shortt free pendulum clock in which an impulse to the pendulum is given every two seconds as compared with every thirty seconds for the Shortt pendulum.

[See *The Horological Journal*, June 1946, p. 234 and February 1959, p. 89.]

429 Campiche master clock

In this electrically driven clock, patented by M. A. and H. Campiche in 1893-9, the pendulum rotates a count-wheel which makes an electrical contact every minute; an impulse is then given to the pendulum by means of a flat spring.

This is believed to be the first clock in which a count-wheel is used in this way. The brief bursts of current can be used to drive a series of impulse dials.

The energy required for making contact is taken directly from the pendulum.

[See *British Patent Specifications No.* 8,830 of 1893 *and No.* 10,393 *of* 1899.]

430 Synchronome master clock

An example of the type of electrical master clock developed and patented by F. Hope-Jones in 1905-7 and since widely used. It is intended to transmit electrical impulses every half minute to a number of distant 'impulse dials', and its design is such that the transmission of the impulses does not interfere with the accurate time-keeping of the master clock. The actual clock exhibited is a relatively modern one, but it differs in no essential feature from the 1907 model.

The pendulum beats seconds, and mounted upon it there is a light hinged arm which is provided with a jewelled pin which at every swing to the right engages with a 'count-wheel' of 15 teeth and turns it through the width of one tooth (at each swing to the left the jewel rides lightly over a tooth of the wheel). The wheel therefore makes a complete revolution every half minute. The wheel carries a vane which once every revolution engages with a catch and releases a hinged gravity arm carrying a roller. This roller then falls upon an inclined face mounted upon the pendulum and, as it rolls down the face, imparts a mechanical impulse to the pendulum. Immediately afterwards a tailpiece on the gravity arm meets a contact mounted upon the end of the armature of an electro-magnet and closes a circuit containing the coils of the electro-magnet and also of the electro-magnets of the connected dial mechanisms. The electro-magnet of the master clock is therefore energised, pressing the contacts together and pushing the gravity arm upward. The armature soon meets a stop, but the momentum of the gravity arm causes it to continue in motion upward until it is again locked upon its catch. The contact is thus sharply broken when the armature reaches its stop.

The method employed ensures an impulse of invariable amount being given to the pendulum every half minute, and gives a decisive 'make of electrical contact, a firm pressure throughout its duration, and a sharp 'break', so that a single well-defined electrical impulse is sent out to the dials.

The Synchronome clock exhibited is serving as a 'slave' to the adjacent Shortt free pendulum clock and is synchronised by means of the Shortt synchroniser.

[See *Electrical Timekeeping*, by F. Hope-Jones.]

431 Synchronome Dial

An example of the impulse dial mechanism employed in the Synchronome system of electric clocks.

electro-magnet, under the action of a spring, and the pawl moves a wheel of 120 teeth, carrying the minute wheel, through the space of one tooth.

A click is mounted on an arm which carries a pin engaging with a semi-circular notch in the lever carrying the pawl, and above the latter there is a stop. This arrangement prevents the wheel being moved more than one tooth at a time, and also ensures that the wheel is positively controlled throughout the operations.

Free Pendulum Clocks

432 Bartrum's free pendulum clock

A clock first described by C. O. Bartrum of Hampstead in 1917, embodying the principle of the free pendulum and slave clock first employed by Rudd in 1899. It was probably the first clock of this type to work reliably.

The free pendulum, on the left, swings freely between impulses, and receives an impulse of a fraction of a second's duration every minute; after the impulse it transmits a synchronising signal to the slave clock, on the right. At the end of the ensuing minute the slave clock releases the next impulse to the free pendulum.

The impulse imparted to the free pendulum is a gravity one of constant amount, and the lever which applies the impulse is released by an electro-magnet operated by the slave clock. As the impulse arm falls away after giving the impulse, it makes an electric contact which transmits a synchronising signal to the slave clock and also actuates an electro-magnet which restores the gravity arm to its rest position. The slave clock then measures out the ensuing period of just under 60 seconds before it releases the free pendulum's impulse arm for the next impulse. As described in an adjacent label, the nature of the synchronising action is such that any error arising in the slave is rocked with decreasing amplitude until it has disappeared and the two pendulums are exactly synchronised again. The synchroniser has the great theoretical merit of correcting both the rate and phase of the slave. The slave clock itself, on the right, is a weight-driven timepiece with dead-beat escapement.

[See *Proceedings of the Physical Society of London*, vol. 29, p. 120, [1917).

433 Bartrum's barometric compensator

Variations of barometric pressure affect the time of swing of a pendulum in two ways. High pressure, leading to high air density, buoys up the pendulum, reducing the effective value of gravity and so slowing the

pendulum; the high density also increases the frictional drag and produces a further slowing effect. The first effect can be calculated fairly accurately, and for a pendulum with brass bob amounts to about 1/5th second per day for each 1 inch rise of the mercury barometer; the second effect depends upon the shape of the pendulum bob, but for a cylindrical bob is roughly equal to the first, so that the total error is about 2/5th sec./day for 1 inch rise of pressure. Bartrum's compensator, first described by him in 1929, is intended to compensate this effect.
It consists of a pile of vacuum boxes (as employed in an aneroid barograph). The bottom of the pile is fixed to the pendulum rod, while the top carries a weight. A rise of barometer causes the boxes to contract under the increased pressure and so to lower the weight. If the compensator is mounted well above the mid-point of the pendulum rod, lowering the weight will speed it up, and the amount of speeding can be adjusted to compensate the slowing described above. The actual movement of the weight is about 1/40th inch for 1 inch change of barometric pressure.
[See *The Practical Watch and Clock Maker*, 15th March, 1929, and *Journal of the British Astronomical Association*, vol. 44, No. 6 (1934).]

434 Shortt free pendulum clock

This type of clock, made by the Synchronome Co. Ltd., was perfected by W. H. Shortt, working in conjunction with F. Hope-Jones and the Synchronome Company, in 1921-4. It forms the practical realisation of the principle of the Free Pendulum and Slave Clock, illustrated by Rudd's pioneer free pendulum clock which is exhibited nearby.
The best mechanical timekeeper known is a pendulum swinging freely under gravity, but in order to convert such a pendulum into a practical clock the pendulum must be sustained in motion, so that its oscillations do not die down, and the swings must be counted. In ordinary clocks the sustaining and counting functions are both carried out by the escapement and clock mechanism, but the free motion of the pendulum is considerably interfered with thereby, with a consequent loss of accuracy in timekeeping.
In the Shortt clock the two functions are carried out by a subsidiary or 'slave' clock—a standard Synchronome clock, which in this case is mounted to the left of the free pendulum. Every half minute the slave clock transmits a short electrical impulse to the free pendulum, energising an electro-magnet which releases a catch and allows a jewel mounted on a light arm to fall upon a small wheel mounted on the free pendulum. As the jewel rolls off the wheel it imparts a light impulse to the free pendulum, this impulse being all that is required to make good the energy lost by the free pendulum during the preceding half-minute. After imparting the impulse the light arm releases a heavier arm which falls into an electrical contact and is restored to its original position by an electro-magnet; the same current which operates this electro-magnet passes through the operating coil of the Shortt synchroniser on the slave clock. The slave clock is thus corrected so that it will release the gravity arm at the correct moment at the end of the next half-minute.

The free pendulum, therefore, swings entirely freely except for the fraction of a second every half-minute during which it is receiving its impulse. The impulse given is strictly constant in amount and is given symmetrically at the mid-point of the swing.
Shortt clocks were the standard timekeepers at Greenwich Observatory from 1925 to 1942, when they were superseded by quartz crystal clocks. [See *Electrical Timekeeping*, by F. Hope-Jones.]

435 Shortt 'Hit-and-miss' synchroniser

This synchroniser, patented by W. H. Shortt in 1921, enables the Shortt free pendulum clock on its right to synchronise this Synchronome clock, which is serving as a 'slave' to the free pendulum.
The pendulum of the slave clock is fitted with a vertical leaf spring which normally swings just clear of a projection on the armature of the synchronising electro-magnet. If, however, the pendulum of the slave is late the armature will be pulled down just before the instant at which the spring is passing it, the two will engage, and the bending of the spring will apply a force to the pendulum which quickens the ensuing half-swing by one two-hundredth of a second. The rate of the slave clock is so adjusted that this process effects approximately twice the amount of correction needed, so that at the expiry of the next 30 seconds the slave pendulum will still be ahead of time and its spring will therefore be just past the tip of the synchroniser at the moment of operation. At the end of a further 30 seconds, however, synchronisation will again be effected. 'Hitting' and 'missing' thus occur roughly at alternate half minutes.

Self-Winding Clocks

436 Self-winding electric clock

Invented by Chesters H. Pond, of Brooklyn, New York, in 1881. It is driven by a small rotary electric motor which winds up a spring hourly.

437 Self-winding electric clock

In this clock, which was invented by Dr. Hermann Aron of Berlin in 1892-4, a light tumbler switch is operated by the running down of the clock train; an armature then rewinds the driving spring and replaces the switch.
This self-winding action was primarily designed to operate the Aron electricity meters, several types of which are exhibited in the Electric Power section of the Museum.

438 Self-winding electric clock

In this clock, made in 1898 by the National Self-Winding Clock Co., USA, the contact for closing the circuit which excites the operating electro-magnet is made by mercury in a small sealed tube.
The electro-magnet is laminated and winds up both 'going' and striking' trains.

439 Hipp impulse dial

In this impulse dial mechanism, introduced by M. Hipp of Neuchâtel about 1860, a pivoted and magnetized armature is made by currents from a master clock to turn through a large angle, swinging alternately from one pole of an electro-magnet to the other. This rocking motion is converted into a rotary motion of the hands by means of a reversed verge escapement.

The master clock sends out a current each minute, the current being alternately in opposite directions. The armature, being permanently magnetized, is attracted alternately to one or the other pole or the electro-magnet.

The purpose of this design is to ensure that the hands of the dial shall not move through more than one minute for each impulse from the master clock. If the contact of this clock is faulty, each impulse may consist of several small bursts of current, and with a dial of the step-by-step type, each of these would be recorded by the dial as a separate impulse. With a dial of the Hipp type, where successive impulses must be in opposite directions in order to be recorded, this type of error cannot occur.

440 Reclus impulse dial

An electrical impulse dial movement patented by Victor Reclus of Paris in 1886.

It is believed to be the first in which the wheel is locked at every stage in the cycle of operations by the use of two clicks only.

With this locking device it is impossible for the momentum of the hands to cause them to over-run and so to move through the space of two teeth for a single impulse.

[See British Patent Specification No. 12,491 of 1886.]

441 'Synchronome' self-winding clock

This self-winding clock, made by the inventors, F. Hope-Jones and G. B. Bowell, in 1895, is an ordinary mechanical clock driven by a weighted lever which is lifted every half-minute by an electro-magnet. For contact-making it employs the 'Synchronome' switch, a type now widely used in master clocks, the essential features of which are that the contacts are pressed together by the force which re-winds the clock and not by forces derived from the pendulum or wheel-work, and that momentum is made use of to secure a quick break. The clock was designed for use as a master clock to drive a number of impulse dials.

The clock is driven by a gravity lever acting upon a pawl and ratchet wheel, and every half-minute the lever as it falls makes contact with the end of a hinged armature. The circuit of an electro-magnet is then closed

The two features—a decisive 'make' and a sharp 'break' of contact—ensure that a single well-defined current impulse shall be sent out to the dials.

[See British Patent Specification No. 1,587 of 1895.]

442 Palmer's impulse dial

An impulse dial of the step-by-step type patented by W. E. Palmer in 1902. It is so designed that the ratchet wheel is locked at all stages of the motion, so that it cannot move through more than the pitch of a single tooth for a single impulse.

On the end of a lever carrying the armature there is a pawl and also a short arm provided with a hole which embraces a pin on a pivoted triangle. The ratchet wheel is normally locked by the arbor of this triangle, but when the pawl moves forward to propel the wheel the triangle rotates so that a notch in its arbor permits a tooth to pass. One corner of the triangle locks against a plate at one extremity of its rotation, so limiting the possible travel of the pawl to the right.

[See British Patent Specification No. 10,541 of 1902.]

443 Morse impulse dial

An impulse dial patented by J. S. Morse in 1903.

Between the poles of an electro-magnet there is a pivoted armature which is normally kept in an inclined position by the action of a weight. When the circuit is closed the armature is drawn into the line joining the poles of the electro-magnet and this partial rotation is made to propel a ratchet wheel by means of a pawl. The pawl is so mounted on the armature that the wheel cannot be moved through more than one tooth at a time.

[See British Patent Specification No. 10,071 of 1903.]

Minute or Half-Minute Time Transmitters

444 Pulsynthetic time transmitter

A modern version, by Messrs. Gent & Co. Ltd., Leicester, of the type patented by I. H. Parsons and A. E. J. Ball in 1904-7. It is designed to transmit electrical impulses every half minute to a number of dials connected in series, all the dials being moved through half a minute at the same time.

It consists of a seconds pendulum carrying a pawl which engages with a count wheel of 15 teeth and pushes the wheel through the space of a tooth every alternate swing. One tooth of the wheel is more indented

445 Electric turret clock

A movement, patented by I. H. Parsons and A. E. J. Ball in 1907, and designed for use in turret clocks which have their hands exposed to the weather and may thus require a variable force for their propulsion. On account of its method of operation it is known as a 'waiting-train' movement. The hands are driven by an electrically maintained pendulum and are automatically set right every half minute by a signal from a master clock The hands move through the space of a half-minute in about 27 seconds, and are then disconnected from the driving pendulum and so remain at rest until the connection is restored by the half-minute signal from the master clock. The clock has two independent electrical circuits: one which maintains the pendulum in motion, and one which re-connects the hands to the driving mechanism every half-minute.

The pendulum is driven by the method invented originally by Hipp, in which it receives an impulse whenever its arc falls below a predetermined value. The pendulum carries a small hinged piece or 'trailer' which moves over a notched piece mounted on a strip spring. With a full arc of swing the trailer moves free of the notch, but when the arc becomes less the trailer does not clear the notch at the end of a swing, and on the return swing the end of the trailer depresses the notch with the strip spring upon it, and closes a circuit through an electro-magnet situated on the right. When energized this electro-magnet attracts an armature which imparts an impulse by striking a projection on the pendulum.

A pawl attached to the pendulum engages with a ratchet wheel and so drives the hands through worm gearing. The length of the pendulum is such that this ratchet wheel rotates once in about 27 seconds, and at the end of each revolution a pin on the wheel lifts an arm which raises the pawl and puts it out of action until the lever is released by an electro-magnet when the half-minute signal arrives from the master clock.

The movement exhibited, made by Messrs. Gent & Co. Ltd., Leicester, is controlled by the Pulsynetic time transmitter on the adjacent wall.

[See British Patent Specification No. 20,878 of 1907.]

446 Impulse dial movement

Designed for operation by a master clock which sends out a brief pulse of current every half minute; it is of a type patented by Major C. E. Prince in 1925 in which a pallet mounted on a pivoted lever carrying an armature engages alternately with the teeth of two wheels which are in mesh.

When the pulse of current from the master clock passes through the electro-magnet, the armature is attracted and the pallet moves across from the right-hand to the left-hand wheel, advancing it through the space of half a tooth. When the current ceases, the armature returns under the action of its spring and the pallet engages again with the right-hand wheel, advancing it through the space of half a tooth, the wheels thus advancing one whole tooth for each half-minute impulse.

The movement is locked in all positions.

[See British Patent Specification No. 227,499.]

447 Impulse dial movement for public dials

Designed for operation by means of pulses of electric current transmitted every half minute from a master clock, and intended to drive the hands of a public dial which are exposed to the wind and weather.

It is of a type patented by S. J. Smith in 1928 in which the operating and backstop clicks are electro-magnetically controlled. The armature rotates through a large angle at each impulse and the operating ratchet wheel has only eight teeth. On account of the worm drive, which is irreversible, no amount of force applied to the hands by wind or snow can move them backwards or forwards.

[See British Patent Specification No. 297,891.]

448 'Magneta' electric master-clock

In this type of master clock, patented by Fischer of Zurich in 1900, the electrical circuit remains closed throughout, and every minute the armature of a simple dynamo, driven by the clock weight, is sharply rotated, sending a pulse of current through the impulse dials. Successive rotations are in alternate directions and so are the pulses of current.

The system has been used to a considerable extent, both on the European Continent and in the United Kingdom.

449 'Magneta' impulse dial

An impulse dial operated once per minute by pulses of current received from the 'Magneta' master clock mounted on the wall nearby.

450 Electric master clock

In the International Superelectric 'supervised' system of electric time indicating and recording the master clock is a mechanical clock with dead-beat escapement which is electrically wound from the mains. The system has been developed mainly for use in controlling the Company's Time Recorders (an example of which is exhibited in a neighbouring showcase) but it is of course used as well for controlling impulse dials or secondary clocks.

Each minute the master clock releases an electric impulse to the secondary clocks and recorders which it controls, and in addition the clock sends out every hour a series of impulses which check or 'supervise' the accuracy of the secondary instruments, stepping up any which may have missed an impulse and therefore be behind the Master Clock, while those which for any reason may have got ahead await a signal to proceed again at the hour. It is not expected that this 'supervising' action will often be necessary, but it serves as an additional hourly check on the accuracy of the controlled instruments.

The system is operated entirely from the mains supply, AC or DC, but even if on any occasion the mains supply should fail for a period the master clock will continue to go, as it has a 12-hour reserve of power. When the electrical supply is resumed, a series of impulses is sent out which steps the dials up until they again show the same time as the Master Clock.

451 Master relay

The impulse contact of the IBM master clock does not deal with the current required for the whole system, but is connected with the coil of a mercury switch, so that the contacts in the master clock have to break the small current necessary to operate this switch. This method ensures long life to the impulse contacts, the full current for operating the secondary clocks passing through the mercury switch.

452 Automatically 'supervised' secondary clocks

These dials are controlled by the International Master Clock on the adjacent pillar; they receive impulses from it every minute and, in addition, a set of 'supervising' impulses every hour. Each dial incorporates a rectifying diode.

The impulses from the master clock are transmitted with positive polarity from each hour up to and including the 49th minute, and in opposite polarity between the 50th and 59th minutes inclusive; and an extra series of impulses is transmitted from the master clock between the 59th and 60th minutes.

The effect of these arrangements is that if an impulse dial is ahead of true time it is held up at the 59th minute until an impulse of the correct polarity arrives exactly at the hour; but if it is slow it is advanced automatically to the 59th minute by the series of impulses arriving between the 59th and 60th minutes.

Hourly Correction

453 Electrically corrected clock

Illustrates a method of controlling a number of clocks which was patented by J. A. Lund in 1876 and used on the Victorian railways in 1892. In this method the hands of the ordinary mechanical clock are corrected every hour by a signal transmitted from a master clock.

The device for correcting the hands is mounted at the top of and in front of the dial; it consists of two pivoted arms attached to the armature of an electro-magnet. Exactly at the hour the signal arrives from the master clock, the armature is pulled down, and the two arms close together, scissors-like, grasping the minute-hand and forcing it to the central position.

[See British Patent Specification No. 3,924 of 1876.]

454 Self-winding clock with hands automatically corrected

This clock, made by the Self Winding Clock Company of New York, is of the type now used on some of London's Underground railways, and

The self-winding mechanism is a modification of that invented by Pond, but in this modified clock the contact is made more frequently and the spring is re-wound by a device similar to an electric bell, the vibratory motion winding up the spring by means of a pawl and ratchet wheel.

Synchronous Electric Clocks

455 Telechron electric timekeeper

This electric clock, patented by H. E. Warren in 1918-24, and made by The Warren Telechron Co., Ashland, Mass., USA, consists of a small synchronous electric motor which is driven by an alternating current electric light supply and the timekeeping depends upon the maintenance of a constant frequency at the generating station. It was the pioneer of clocks of this type.

The motor has a bi-polar field magnet which is energized by a coil connected by a plug with the supply circuit. Shading coils are carried on the pole pieces, the effect of these being to produce a rotating magnetic field, and a disc-shaped rotor is employed which rotates in exact synchronism with the rotating field. The rotor is connected by gearing with the clock hands, and the rotor and gearing are contained in an enclosed casing which includes an oil bath.

An indicator is provided to draw attention to any interruption of the current supply.

The example shown is for use on a supply at 110 volts and a frequency of 60 cycles per second (the standard frequency employed in the USA); it consumes two watts.

456 'Synclock' synchronous electric clock

An example of the first type of synchronous clock to be marketed in the United Kingdom, in 1931.

The synchronous motor is of the Warren type with shaded poles, and as this is a self-starting type an indicator is provided to show if there has been any interruption of electric supply. The rotor and gearing system, which is shown sectioned in a neighbouring exhibit, is enclosed in an oil-bath.

Made by Everett, Edgcumbe & Co. Ltd.

457 Sectioned movement of 'Synclock'

Shows the mechanism of a 'Synclock' in which the casing which is normally sealed and filled with oil has been cut away to show the rotor and gearing.

The electric motor is of the 'Warren' synchronous type. This motor has a laminated field magnet which has four poles. One pair of diametrically

round in this field, making one complete revolution in a double alternation of current.

In an ordinary 'Synclock' the motor is geared down so that the minute-hand arbor makes one complete revolution per hour when the motor is fed with 50-cycle alternating-current. In the sectioned movement shown, however, some of the gearing is omitted and a hand is fitted which makes one revolution per second.

Made by Everett, Edgcumbe & Co. Ltd.

458 Synchronous electric clock

An early (1931) example of a British synchronous clock which is not self-starting.

It is driven by a 12-pole synchronous motor, the rotor of which makes 250 revolutions per minute when connected to a 50-cycle AC supply.

A simple hand-starting device is provided.

Made by Smiths English Clocks, Ltd.

459 Synchronous electric clock

The skeleton movement of an early British synchronous clock of the non self-starting type.

The rotor is of soft iron and has 36 poles: it runs in self-aligning bearings provided with a small reservoir for lubricant. It is fitted with a flywheel, so that a very brief interruption of electric supply will not cause a stoppage.

The clock is provided with a simple hand-starting device.

Made by Ferranti, Ltd.

460 Synchronous motor clock with spring reserve

A combination of a synchronous motor clock and a spring-driven escapement clock.

Normally the movement is driven by the synchronous motor, but if the mains supply should fail the escapement starts and continues to drive the movement until the mains supply is re-established. The balance-wheel of the escapement clock is provided with an armature which holds it in a position at the end of its swing as long as an electro-magnet is energised, but releases it when the electro-magnet is de-energised.

Provision is made for 'exercising' the escapement clock every day even if the mains supply is uninterrupted.

The electro-magnet attracting the balance wheel armature is fed through a rectifier, and every $12\frac{1}{2}$ hours this rectifier is short-circuited for about ten minutes, allowing the escapement clock to run for this period.

If this daily 'exercise' were not provided the oil in the escapement clock would be liable to congeal during long periods of inactivity, so that the clock would not be ready to start when called upon to do so by a mains failure.

461 Synchronous timepiece movement

Clocks of this type, with panel indication of the time, are useful in such places as telegraph offices, where the time to the nearest whole minute

has to be entered in a register by a clerk. The change-over from one figure to the next takes about three seconds.

462 Comparison clock for power stations

A type of instrument used in modern power-stations in order to keep a check on the average frequency of the alternating-current so that synchronous clocks connected to the supply will show correct time. As described in the adjacent large-type label, it consists of a combination of a standard clock and a synchronous clock, arranged to indicate on the same dial so that they may easily be compared.

The inner rotating dial is driven by a synchronous motor and indicates the so-called 'frequency time' shown by all synchronous clocks connected to the supply, while the seconds-hand is driven from the same motor through a slipping clutch, and is automatically set right every half minute by a signal transmitted from a master clock. The seconds hand accordingly indicates standard time, and the amount by which frequency time differs from this can be read off at once from the position of the seconds hand relative to the rotating dial.

Subsidiary dials are provided with minute and hour hands indicating standard time on the one and frequency time upon the other.

Electric Watches

463 Electric wrist-watch

An example of the pioneer Hamilton watch of 1957 in which the current-carrying coil is mounted on the watch balance, and a permanent magnet is mounted on the frame.

464 Swiss electric wrist-watch, calibre L-4751

465 'Accutron' electric wrist-watch

The timekeeping element of this watch is a tuning fork vibrating 360 times per second.

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The elastic vibrations of quartz crystals are accompanied by small electrical effects, and the resulting electrical oscillations can be maintained and magnified by valve amplifier circuits. The oscillations are even more regular than those of the best pendulum clocks, and by means of electrical gearing they can be counted and recorded on a dial in a way similar to that which a mechanical clock counts and records the number of swings of a pendulum.

466 Quartz crystal clock

Three independent Quartz Crystal Oscillators with associated Frequency Dividers, Clock Motor, and Indicators are included in this exhibit, together with apparatus for supplying electrical power to the valve circuits.

The oscillations of the Quartz Crystal, 100,000 per second, are maintained by a valve amplifier circuit in the Quartz Crystal Oscillator. The effects of changes of air pressure and temperature on the rate of vibration of the crystal are very much reduced by mounting it in a vacuum in a sealed container and by controlling the temperature of the container to within 1/500th of a degree Centigrade. The operation of the temperature controls is indicated by the red lamps, which flash on and off as the supply of heat is regulated.

The electrical oscillations generated by the vibration of the Quartz Crystal are reduced from 100,000 per second to 50 per second by means of valve operated devices known as Frequency Dividers. These may be regarded as electrical gear trains. The division is made in stages of 100,000 to 10,000, 10,000 to 1,000 and 1,000 to 50 oscillations per second.

The electric current from the Frequency Divider is amplified and its oscillations are counted by passing it through the coil of an electro-magnet associated with a toothed iron wheel. The current pulls one tooth past the magnet for each oscillation so that 50 teeth are pulled past in each second, and the toothed wheel drives the clock hands through mechanical gearing.

The time error of one Quartz Crystal Oscillator relative to another can be measured accurately by electrical circuits. Three such circuits compare the Quartz Clocks mounted in this case, and the results are shown by the meters on the Clock Error Indicator.

467 Cold-cathode tube frequency divider

This unit further divides the 50 c/s output from the Multivibrator frequency divider, giving a final output of one pulse per second. The

connected that a pulse applied to both tubes causes the tube already conducting to be extinguished and the other tube to become conducting. Each tube therefore conducts every 1/25th second and the output from one is fed through another driver to a ring of five tubes.

In a similar manner to the first pair, the discharge transfers from one tube to the next at each pulse and therefore the pulse output from any one tube in the ring has a frequency of 5 c/s. A further ring of five tubes gives a final output pulse at a frequency of 1 c/s which can be used in conjunction with other electronic equipment for various purposes, for example, to give time signals.

468 The quartz crystal clock

A complete quartz crystal clock is shown in operation in a showcase near by, and the exhibits in this desk case show the ways in which the crystals are selected, prepared and mounted for use in such a clock. The exhibit includes examples of artificially grown quartz.

11 The Atomic Clock

469 The Caesium atomic clock

This 'clock', designed and constructed at the National Physical Laboratory in 1955, measures time by counting the vibrations of caesium atoms. Each atom behaves as a small magnet, and as it passes along the tube from left to right it is deflected by two fixed magnets. Between these two it is subjected to a field alternating at a very high frequency, and if this is exactly equal to a natural frequency of the caesium atom, the atom turns over and when it reaches the second magnet it is deflected back on to the detector.

The alternating field comes from a quartz crystal clock, which can thus be tuned exactly to the atomic frequency. The tuning is so accurate that the time derived from this atomic clock was correct to one second in three hundred years; its successor, now in use at the National Physical Laboratory, is at least six times as accurate.

[See L. Essen and J. V. L. Parry, Phil. Trans. A. vol. 250, pp. 45-69 (1957).]

470 The complete atomic clock

The photograph shows the complete atomic clock in operation at the National Physical Laboratory at Teddington, Middlesex.

In the foreground is the main apparatus itself which you see near by; against the far wall are the quartz clock and accessory electronic apparatus which is tuned to the natural frequency of the caesium atoms. The wave-guide connecting the two groups of apparatus can be seen, traversing the centre of the room. Cables are also seen bringing current to the fixed magnets, the caesium oven and the coils with light-coloured wrappings which serve to cancel out the earth's magnetic field.

471 Animated diagram of the Caesium atomic clock

Caesium atoms are evaporated from an oven at the left-hand end of the diagram.

Each atom behaves as a small magnet, and as it passes along the tube from left to right it is deflected by two fixed magnets. Between these two it is subjected to a field alternating at a very high frequency, and if this is exactly equal to a natural frequency of the caesium atom, the atom turns over and when it reaches the second magnet it is deflected back on to the detector.

The alternating field comes from a quartz crystal clock, which can thus be tuned exactly to the atomic frequency. The tuning is so accurate that the time derived from the latest (1960) atomic clock is correct to one second in two thousand years.

472 Sharpness of tuning

The chart shows the very high accuracy with which the caesium atomic clock can be tuned to the natural frequency of the caesium atoms themselves. It relates to the 1955 atomic clock.

The frequency of the input oscillations is plotted horizontally, and the response of the detecting meter vertically. The width of the resonance peak at half its height is 350 cycles per second, and the peak itself can be located to an accuracy of one cycle per second. The accuracy of the tuning is thus to one part in 10^{10}, corresponding to an error in rate of a clock of one second in three hundred years.

473 A check on the Earth's rotation

The caesium atomic clock is able easily to detect variations in the rotation of the earth.

The vertical scale of the chart shows the difference between the length of the day as determined by astronomical observations and that derived from the caesium clock, expressed in milli-seconds, over a period from July 1955 to November 1960. It is seen that the astronomical day is relatively long in spring and late autumn each year, and relatively short in the summer, and there is also a general drift from year to year, with a maximum around 1959. These effects have not yet been fully explained by astronomers and geophysicists.

12 Chronoscopes and Chronographs

These are instruments used for measuring short intervals of time, such as the duration of a race, or for recording the exact instant at which some event—such as the transit of the sun or of a star across the meridian—takes place.
Chronoscopes are devices in which a train of wheels is kept in continuous motion, while an indicating hand can be thrown into or out of gear with it by means of an electro-magnetic clutch.
Recording chronographs are instruments in which a strip or sheet of paper is drawn uniformly beneath a pair of recording pens, one of which is deflected by means of an electro-magnet at the instant to be determined or at the beginning or end of the interval to be measured, while the other pen is operated at regular intervals by means of signals transmitted from a clock and so marks a time-scale upon the record.

474 Hipp chronoscope

(*See Plate 12*)

An instrument made by M. Hipp of Neuchâtel, and designed for measuring short intervals of time to an accuracy of 1/1000th of a second. It consists essentially of a weight-driven train of clockwork, in which the rate of rotation of the escape wheel, instead of being governed by a pendulum, is controlled by a metal reed which vibrates 1,000 times per second. When in use, the clockwork is kept continuously in motion, and the indicating mechanism is thrown into or out of gear with it by a simple mechanical clutch operated by a pair of electro-magnets. The instrument is suitable for use in experiments on the velocity of projectiles, where the projectile is made to break different electrical circuits at different points of its path.
The vibrating reed is clamped within a block whose position can be carefully adjusted by means of two screws so that the tip of the reed just touches the escape wheel when at rest. When the escape wheel is in motion it sets the reed vibrating, and the wheel accelerates until its rate of rotation is such that one tooth passes beneath the reed for each complete vibration of the latter.

475 Millisecond stop clock

The electronic equivalent of a stop watch, started and stopped electrically. As shown it will measure intervals of time up to one second to an accuracy of one-tenth of a millisecond (i.e. one ten-thousandth of a

second) and as normally supplied, with an additional mechanical counter, the measurable interval is increased to 100,000 seconds (over 24 hours).
Its basic time-measuring equipment is a crystal oscillating 10,000 times per second. Pulses from this oscillator are counted and recorded on the right hand dial of the instrument; every tenth pulse from this dial on the next one, and so on.
The clock is 'started', i.e. impulses from the oscillator fed to the first dial, by an electrical 'gate' and is stopped similarly.
The stop-clock is being used in this demonstration to measure the intervals between 'makes' of contact on a rotating telephone dial. It will be seen that these are approximately multiples of 0.9 second.
To re-set the stop-clock, press the push-button.

476 Bashforth's chronograph

This chronograph was invented by the donor about 1865, and was used for measuring the times occupied by projectiles in passing over a succession of equal spaces.
The instrument consists of a fly-wheel which can be rotated by hand about a vertical axis and carries a cylinder with a prepared paper surface. A platform, to which two electrically operated markers are attached, is mounted on a slide by the side of the cylinder and is caused to descend slowly by means of a cord wound around a drum which is geared with the axis of the fly-wheel. The markers trace spirals on the cylinder and are controlled by means of two electro-magnets, the upper of which is in circuit with a number of screens through which the projectiles pass. The passage of a projectile through each successive screen causes a corresponding interruption of the current and is recorded by a deflection of the marker upon the surface of the cylinder. The circuit of the lower electro-magnet is interrupted once a second by a clock beating half seconds and the lower marker consequently gives a time scale.
Each screen consists of a series of cotton threads suspended from the ends of brass spring wires and extended by means of weights at the bottom. The distance between adjacent threads is less than the diameter of a projectile, and the spring wires pass through holes in vertical copper plates. The circuit is closed by the contacts between the spring wires and the copper plates, but when a thread is cut by a projectile the circuit is broken for a short interval while the corresponding spring flies from the bottom to the top of its hole.
This instrument was used in experiments referred to in 'Reports on experiments made with the Bashforth chronograph to determine the resistance of the air to the motion of projectiles, 1865-1870'. Generally 10 screens were used a intervals of 150 feet.

477 Tape chronograph

In this instrument the tape on which the record is made is unwound from a spool and drawn past the recording pens by means of a pair of rollers. The rollers are driven from an induction-type electric motor

whose speed is controlled by a centrifugal governor of the type commonly employed in gramophones. The drive takes place through a gear-box, which enables the speed of the moving paper to be maintained at $\frac{1}{2}$ inch or $1\frac{1}{2}$ inches per second as desired.

Each recording pen consists of a fine metal tube, one end of which rests on the paper, while the other end dips into a small vessel containing ink. The ink is drawn up through the pen by capillary action and issues from the end resting on the paper. Each pen is mounted upon the armature of a small electro-magnet, and is deflected whenever a current (of about $\frac{1}{2}$ ampere) is passed through the electro-magnet. One pen is actuated every second from a clock contact.

The record when completed is removed from the chronograph and the position of the break or breaks recorded by the observer is compared with the neighbouring scale of seconds recorded from the clock or chronometer. In this way the exact instant of transit of a star or the duration of a race can be found with an error of a small fraction of a second.

478 Tammeter

A device for registering the times at which a television receiver is in operation, developed by Mr. Bedford Attwood.

It records on a tape the precise times at which the receiver is switched on, to what channel it is tuned, and when it is switched off.

The actual recording is a visible one on a metal-coated tape driven at a speed of $1\frac{1}{2}$ inches per hour, and there are six recording styli to allow for various channels.

When the sign 'BBC' is illuminated, the second stylus or pen would be marking its tape, when 'ITV', the fourth pen.

TAMMETERS are placed in homes selected to make up a representative panel in each television area.

The tapes are removed at intervals of a week and analysed to give detailed or statistical information about viewing times.

479 Records from tammeters

The exhibits include: specimens of tape records; sample cards showing the ON/OFF change in punching and a BBC/ITV change-over; a specimen report; and a specimen large-size sheet.

13 Time Recorders

These are instruments which make a printed record of the time of day at which a certain event takes place. They are most widely used for registering the time of arrival and departure of employees, but they can also be utilised for a variety of other purposes, such as to record the times at which omnibuses pass a definite point, to check the rounds of a night-watchman, or to register the times at which a safe, strong-room or shop is locked or unlocked or at which jobs are started and finished. Photographs of pioneer time recorders are exhibited, together with examples of early and modern instruments.

480 Watchman's clock

This early nineteenth-century clock, by Bellefontaine of London, is of the type which was used by a nightwatchman to prove that he had kept awake.

It sounded one stroke on a bell every quarter-hour and as soon as possible after this the watchman depressed the knob on the top of the clock. This action drove in the pin which lay at that instant below the knob, and as the disc carrying the pins rotated a visible record was thus given of the times at which the knob had been depressed, thus proving that the watchman had been awake at these times.

The mechanism can be seen in more detail in the movement, shown on the left, of a similar watchman's clock; this one is provided with pins only every half-hour, and has no alarm bell.

481 Photographs of 'Bundy' time recorder

These show the earliest form of workmen's time recorder, invented by W. L. Bundy in the USA in 1885. It consists of a mechanical clock which rotates a set of type wheels and is operated by any one of a series of numbered keys, one of these being issued to each employee. The process of turning the key in the key-hole in the front of the machine brings the engraved number on the key in line with the time as indicated by the hour wheel, and the record is then stamped on a continuous roll of paper. The employee's number thus appears against the time he has recorded, while the records of different employees appear in the order of their arrival and departure.

In the earliest Bundy recorders the time was shown only to the nearest hour, but in later models minutes as well were recorded.

The Bundy recorder is now almost obsolete, but many examples are still in use, particularly as traffic recorders on tramway and omnibus routes.

482 Photograph of dial time recorder

The photograph shows the earliest dial type recorder invented in 1888 by Alexander Dey of Aberdeen. In this type of machine the records made by different employees appear in their numerical order, instead of in chronological order as in the earlier 'Bundy' recorder.

483 'Supervised' electric card time recorder

This machine prints automatically on separate cards a tabulated record of the times of arrival and departure of employees. When a time card is placed in the slot in the front of the recorder it automatically prints on the card in the correct position the day, hour and minute of the operation. A completed card is exhibited adjacently. The cards are usually kept in numbered racks at the side of the machine.

The clock is operated electrically by impulses received from the International master clock mounted on the pillar nearby. An impulse is received every minute, and this advances the time-indicating numerals and also advances the minute type wheel in the mechanism, which advances the hour type wheel at the 60th minute, which in turn periodically advances the day type wheel.

When a card is inserted, the printing hammer presses the card against the ink-ribbon, which is immediately in front of the correct time portion of the type wheels, and the correct time is thus printed on the card. The red records on the card indicate lost time and overtime. The times for the operation of the colours can be set to any schedule, and a similar mechanism sets the recorder for the correct position IN or OUT and also for the correct line corresponding to the day on which the record is made.

The recorder exhibited is operated and controlled entirely from the master clock.

484 The 'Printime' time stamp

A stamp for recording the exact time that letters, telegrams, orders, telephone messages, etc., are received, documents filed, jobs start and finish, visitors call and depart, cars enter or leave garages, etc.

The stamp is controlled by the International Master Clock near by, and is operated by a slight finger touch.

485 Magneta time recorder

A modern card time recorder, driven by a synchronous electric motor, which prints automatically on separate cards the times of arrival and departure of employees.

It is very adaptable, and over 500 variations can be obtained to meet the requirements of the various shapes and sizes of time cards in use today. The recorder is provided with a signal switch and week-end cut-out which can operate bells, buzzers, hooters or radio systems at predetermined times, and automatically ensures that these signals do not operate at periods when they are not required, such as week-ends.

486 Watchman's control clock

For checking the patrol of night-watchmen.

Numbered station keys are installed at suitable points and the watchman carries the clock around with him. As he arrives at each key station he records his time by inserting and turning the recording key in the clock. Thus, locked away inside the case, where there is no possibility of its being tampered with, there is a neat, easily read record of the time and number of the station.

The movement of the clock operates for 72 hours at one winding and is housed in a tamper-proof metal case.

14 Alarm, Striking and Repeating Mechanisms

Alarm and striking mechanisms are devices which are released by a timekeeper at a pre-set hour. An alarm rings a bell or sounds some other warning, while a striking mechanism causes the appropriate number of strokes to be sounded upon a bell or gong each hour.
Repeating mechanisms give, upon demand, an audible indication of the time, to the nearest hour, quarter or minute. They are usually incorporated in the movement of a clock or watch, but have also been made in detached form, for coupling to a non-repeating clock or watch.
This section of the Collection illustrates the mechanisms involved; actual watches fitted with them are embodied in the main watch collection. (See Catalogue Nos. 244 to 251 and 359 to 379.)

487 Lantern alarm timepiece

Signed 'Thomas Knifton at the Cross Keys, Lothbury'. It has a verge escapement and short 'bob' pendulum, and is provided with an alarm. The chapter-ring is divided into hours and quarters, and there is an hour-hand only.
Knifton was free of the Clockmakers' Company from 1640 to 1662.

488 Alarm attachment for key-wound watches

An apparatus, of French manufacture, intended for use with the old type of key-wound watch, enabling such a watch to sound an alarm at a specified time. The device consists essentially of a table for supporting the watch, a spring-driven alarm bell and a releasing mechanism, and its operation depends upon the fact that as the watch goes the squared winding arbor rotates.
A key which fits upon the winding arbor of the watch rotates clockwise with this arbor and carries an arm which moves a ratchet wheel through the space of one tooth for every rotation of the key. At the completion of a revolution of this wheel an arm rotating with it pushes aside a small pivoted lever which releases the L-shaped arm and permits the alarm bell to ring.
The time at which the alarm rings depends on the initial setting of the key and of the ratchet wheel, and so can be varied in steps.

489 'Memopark' pocket timer

The timer is an alarm which can be set to operate for periods up to one

hour, and is intended for use by a driver who has left his car at a parking meter.

490 Striking clock movement

An English clock movement, made about 1880, with a locking-plate or count-wheel striking mechanism similar in principle to the striking arrangements of the earliest known clocks of the fourteenth century.
In this example the locking plate consists of a circular flange with a number of gaps, the distance between the successive gaps being proportional to 2, 3, 4, 5, etc. up to 12. The striking train of wheels is locked when the bent end of a lever falls between one of the gaps. In detail the series of operations involved in striking are somewhat complicated, but it is the distance between successive gaps which determines the number of blows struck. As the locking plate moves with the striking train, its position is independent of that of the hands, and when the latter are moved it is necessary to wait for the striking at each hour.

491 Striking clock movement

An English clock movement, made about 1880, with the rack-striking mechanism, which was invented by the Rev E. Barlow in 1676 and applied to clocks with the assistance of Thomas Tompion.
This mechanism is the form now generally used for domestic striking clocks, and it has the advantage, in comparison with the older locking plate striking mechanism, that the hands may be moved without waiting at each hour for the full number of strokes to be struck.
The position of a stepped spiral plate or 'snail', which moves with the hour hand, determines the number of strokes on each occasion.

492 Detached repeating mechanism for use with a bracket clock

An eighteenth-century apparatus intended for use as an accessory to a bracket clock, enabling it to repeat the hour and nearest quarter whenever required. For this purpose the pinion on the projecting spindle of the apparatus is made to mesh with one of the motion wheels of the clock, so that the pinion is rotated once per hour by the clock.
On the same spindle as the pinion is a stepped cam which controls the number of quarters to be struck; this cam carries a pin which engages with the star-wheel every hour and moves it through the space of one tooth. On the same spindle as the star-wheel is a 'snail' which controls the number of hours to be struck.
If the positions of the snail and cam are correctly set in the first place the mechanism will repeat the hour and nearest quarter whenever the cord is subsequently pulled.

493 Detached repeating mechanism for use with a key-wound watch

A mechanism, patented by Trusted in 1796 and made by Court of Henley, designed to be controlled by a key-wound fusee watch, and

when so used sounds the hour and nearest quarter whenever required. Its action depends upon the fact that with this type of watch the winding square rotates as the watch goes.

From the table upon which the watch rests a slotted spindle projects which fits over the winding square of the watch and is driven by it. As the spindle rotates, a pinion co-axial with it drives a straight rack which can slide in a horizontal direction and controls both the hour and the quarter striking.

[See British Patent Specification No. 2148 of 1796.]

15 Gas-controllers and time switches

From the horological point of view these may be compared with alarm and striking mechanisms, but instead of giving an audible signal at a pre-set hour they perform a definite control operation such as turning on or off a gas-cock or an electric switch.

Their main field of application is in switching street-lamps on at dusk and off at dawn, but they can also be used for domestic heating or cooking, in a variety of industrial processes, and in fact whenever an operation is required to take place at a specified time, or after a specified time interval.

494 Reconstruction of Thurgar's pioneer gas-controller of 1867

A modern reconstruction of a device patented by Dr Thurgar of Norwich in 1867 which has been constructed according to the description given in the patent specification. The device is a clockwork controller running for eight days at each winding and is designed to turn the gas supply to the lamp on and off at pre-determined times. With the gas cock in the 'off' position a special channel allows a small quantity of gas to pass, so that a small blue flame is left burning during the day-time. In order to screen this small flame from draughts, the controller automatically raises a small protecting globe as the gas is turned off and lowers the globe again as it is turned on.

Examples of Thurgar's controller were installed at the Mint and at Somerset House but they have now disappeared and no original example is known to exist.

[See British Patent Specification No. 2435 of 1867.]

495 Example of Gunning's first gas-controller for street-lamps

This clockwork device, patented by Gunning in 1897, was designed to be wound up by the lamplighter at dusk in the act of turning on the gas, and itself turned off the gas automatically a given number of hours afterwards, so that a second daily visit from the lamplighter during the night or early morning was rendered unnecessary.

Each evening at dusk the lamplighter pulled down the chain; this action rotated a pulley-wheel in an anti-clockwise direction, thus winding up the driving spring of the clock mechanism, which then commenced to drive the wheel slowly in a clockwise direction.

This device was soon superseded by the fully automatic controller exhibited adjacently.
[See British Patent Specification No. 7011 of 1897.]

496 Example of Gunning's first fully automatic gas-controller

Patented by Gunning in 1899 and the first commercially successful fully automatic controller, turning the gas on as well as off. A small by-pass with continuously burning flame was provided in order to light the main burner when its supply was automatically turned on by the controller.
The times at which the gas was turned on or off could be varied in steps of one hour to suit the season of the year by suitably adjusting the positions of two arms.
The controller requires weekly winding and adjustment of the arms at somewhat rarer intervals.
[See British Patent Specification No. 25567 of 1899.]

497 Electrical time-switches

The mechanism of the early time-switch on the left is identical with that of the first Horstmann gas-controller, patented in 1904-5 and described in an adjacent label, but in the time-switch the operating crank is connected to an electric tumbler switch instead of to the plug of the gas-cock. The switch is of a type first introduced about 1905.
The later time-switch on the right is driven by a synchronous electric motor and is suitable for use in localities where the alternating-current electric supply is time-controlled. The switch is fitted with the Horstmann solar dial giving continuous automatic adjustment of the switching times to suit the season of the year. The contacting gear is robust and gives a quick break of contact. The time indicator has two pointers marked 'W' and 'S' for use during winter and summer times respectively.
[See British Patent Specifications Nos. 27849 of 1904, 27290 of 1905 and 395813.]

498 Early Horstmann gas-controller fitted with a 'solar' dial

An example of the first type of Horstmann gas-controller for street lamps, and believed to be the first controller fitted with a 'solar' dial, a device, patented in 1904, which automatically adjusts the position of the controlling arms according to the season of the year, so that the street lamps will be lighted at dusk and extinguished at dawn throughout the year.
This was probably the first controller giving quick action—a desirable feature preventing the risk of 'lighting back' when used with incandescent burners.
[See British Patent Specifications Nos. 27849 of 1904 and 27290 of 1905.]

499 'Solar' dial used in automatic switching of street-lamps

Clocks with dials of this type are used for automatically switching on electric street lamps at sunset and switching them off at sunrise. The dial as a whole is rotated by the clock once every 24 hours, and the actual switching is carried out with the aid of two arms mounted on the dial whose positions relative to the dial are automatically varied according to the season of the year, so as to allow for the variation in the times of sunset and of sunrise. The dial exhibited shows the way in which this adjustment is made.
Made by Venner Time Switches Ltd.

500 Street-lighting: manual control

The diorama shows the way in which gas street lamps were lit individually by hand before automatic clock-controlled switching was invented.

501 Street-lighting: the modern way of switching

This exhibit shows the way in which a modern time-switch with solar dial controls the switching of street lamps.
In the normal instrument the solar dial is rotated by a synchronous motor once every 24 hours, but in the clock exhibited here some gearing has been omitted, so that the dial rotates once per minute.
The switching is carried out by means of pins mounted on the three arms of the dial; the position of two of these relative to the dial is automatically varied according to the season of the year, so as to follow the changing times of sunset and sunrise, while the third pin is fixed to operate at a selected time adjustable between 11 p.m. and 1 a.m. The switch controls two separate electrical circuits: both are switched ON at sunset, and one is switched OFF at the chosen time between 11 p.m. and 1 a.m.; the other goes OFF at sunrise. Details of the switching action can be seen by watching the switch at work; it will be noticed that both 'make' and 'break' are rapid.
The street lamps in the diorama are controlled by the circuit switching OFF at midnight.

502 Electrically wound triple-pole changeover time-switch

This modern time-switch is fitted with a dial to give three ON and three OFF switchings daily, and a selective device to enable one or more of these switchings to be omitted on a chosen day or days.
The example shown is operated by a mechanical clock electrically wound from the A.C. mains supply, but other models are available which are respectively hand-wound, synchronous motor-driven, and driven by a synchronous motor with 30-hour spring reserve which comes into operation if the mains supply fails.

503 Modern programme clock

The notable feature of this programme clock, which provides pre-set

automatic switching for a whole week, is the ingenious way in which the switching programme is set.
A spring-driven clock movement drives a 14-grooved drum which makes one revolution every 12 hours. The particular groove or 12-hour period in operation is shown in an aperture at the side by the day name; 0 to 12 hours (midnight to midday) by black letters on a white ground and 12 to 24 hours (midday to midnight) vice-versa. The drum can be rotated manually by the glass disc on the face of the clock.
A small container housing 50 steel balls is mounted at the side of the drum and is moved transversely the width of one groove every 12 hours, by a pin on the drum engaging with oblique slots on the container. Incorporated in the container is a mechanism, operated by the lower front knob, for pressing the steel balls into the grooves, which are 0.03 mm smaller than the balls.
The balls on the drum form a series of projections and, as the drum revolves, operate a micro-switch mounted on the ball container.
Removal of the balls after they have carried out their switching is achieved by causing a plastic comb to rest in the drum grooves; when the drum is then turned anti-clockwise the balls are forced from the grooves and fed back into the container.

504 Programme cabinet

A cabinet for the control of heating and ventilation systems, lighting, electric ovens, radiators, outdoor signs of public address or radio systems, adjustable to the individual minute, and can, if required, give a different programme for every day of the week.
The lower drum makes one revolution every three hours, and the upper drum rotates once per week.
The cabinet is controlled by the International Master Clock near by.

16 Miscellaneous

505 Clock movement showing fusee

The fusee is a device for obtaining a constant driving torque from a spring as it uncoils, and has been widely employed in clocks, watches and chronometers.
It consists of a tapering drum with a spiral groove cut in it, and the pull of the mainspring is exerted through a cord or chain which is unwound from this groove on to the outside of the drum or 'barrel' containing the spring. When the spring is fully wound and exerting its greatest pull the cord is unwinding from the smaller end of the fusee, where it has only a small leverage, while when the spring is nearly run down the chain pulls at the wider end of the fusee, with a greater leverage. By suitably shaping the fusee the torque on its axis can be made quite uniform for all states of the spring.
In the early foliot clocks of the fourteenth and fifteenth centuries the rate of the clock depended largely upon the magnitude of the driving force. When the first spring-driven clocks were made, probably towards the end of the fifteenth century, it became essential to find some means of obtaining a constant driving torque from an uncoiling spring.
There is some evidence for spring-driven clocks with a fusee as early as 1450, and the fusee mechanism is shown in sketches made by Leonardo da Vinci in 1490, but the earliest fusee clock which can be dated with certainty is one made by Jacob Zech in 1525.
The application of the pendulum to clocks about 1660 and the balance-spring to watches about 1670 and the subsequent invention of better escapements caused the timekeeping of clocks and watches to be less affected by variations in the driving force, and hence the fusee was no longer essential and its use has therefore been to a large extent discontinued, though it is still almost invariably employed in chronometers, in which the highest accuracy is essential.

506 Skeleton timepiece

A French timepiece made about the middle of the nineteenth century and including a number of interesting features. It has a centre-seconds arrangement, a pin wheel escapement, a gridiron compensation pendulum and a weight remontoire.
A remontoire is a device for obtaining a constant driving force on the escapement and in this example, though not always, it is employed as a substitute for a fusee. The main driving train is arranged to wind up, about every 16 seconds, a subsidiary system which in turn drives the escapement.

The remontoire is introduced between the third and fourth wheels of the train, and the subsidiary driving system consists of a weight on the end of a lever which is connected by an endless cord with pulleys mounted on the arbors of the third and fourth wheel. The action of the weight drives the fourth wheel and the weight is lifted up by intermittent motion of the third wheel.

507 'Atmos II' self-winding clock

A clock automatically wound by changes of atmospheric temperature and pressure. A fall of temperature of 3°F provides enough power to drive the clock for over 24 hours.

The driving motor of the clock, a sectioned example of which is shown on the left, consists of a drum on the inside of which is mounted a flexible metallic bellows. The space between the bellows and the outer drum casing is hermetically sealed and contains ethyl chloride, the vapour pressure of which varies very rapidly with temperature. Increase of temperature raises this pressure and causes the bellows to expand against a spring. A similar effect would be produced by a fall of barometric pressure. By means of a connecting system, the expansion and contraction of the bellows is caused to wind up the clock mainspring, which has a year's reserve of power. Arrangements are made to prevent overwinding and the mainspring normally operates under nearly uniform tension.

The design of the clock itself has many features of interest.

The horizontal balance wheel is controlled by an elinvar spring, whose elasticity does not vary appreciably with temperature. The balance, which is driven by a detached lever escapement, makes only 1440 oscillations in 24 hours, compared with 43,200 for a seconds pendulum. Owing to the slow action of the moving parts and the precision of their finish, the use of oil in the clock has been entirely eliminated.

508 Oil painting of Harrison

A painting by T. King of John Harrison (1693-1776), the great pioneer of marine timekeepers.

509 Oil painting of Earnshaw

A painting by Sir Martin Archer-Shee of Thomas Earnshaw (1749-1829), a pioneer in chronometer manufacture.

17 List of the more important objects in the reserve collection

As mentioned in the Introduction to this volume, most of these objects may be inspected on written application to the Director and Secretary, the Science Museum, South Kensington, London, S.W.7, provided that sufficient notice is given. Some are stored in the Museum itself, and fairly readily accessible, others are in outlying stores.

They include further sand-glasses from the Abbot Horne Collection and pocket sundials presented to the Museum in 1938 by W. E. Miller, Esq.

Sand-glasses and other non- mechanical devices

R1 24-inch hour-glass: in wooden mount.

R2 Chinese incense clock.

R3 21½-inch sand-glass: in wooden mount.

Sundials

R4 Plaster cast of ancient stone sundial.

R5 Horizontal sundial: dated 1624, and shows the time of day and the length of the day in hours. A volvelle (a later renewal) shows the difference between solar and lunar time according to the age of the moon.

R6 Slate dial-plate of a horizontal sundial showing Italian hours.

R7 Azimuth sundial: this early eighteenth-century dial indicates the time by means of the direction of the sun and is said to have been made by Rudolph Gleich, Vienna.

A pewter dial plate is mounted on a wooden base with spandrel ornaments, and is marked with a series of hour lines. A hinged arm turning on the centre of the plate carries at one end a vertical style and at the other a pointer which can be made to slide radially along the arm by means of a rack and pinion connected with a hand which moves over a scale of months.

In use the instrument is oriented, the hand set for the date, and the arm moved until the shadow of the style falls horizontally along the arm. The pointer will then show the time on the appropriate hour scale.

I

R8 Orthochronograph: made by Messrs. R. Webster & Son. A portable instrument for ascertaining correct time by observing equal altitudes of the sun before and after it crosses the meridian. The principle was suggested by Mr. Lowman and the apparatus was exhibited at the British Association Meeting in 1844.

R9 Brass portable sundial: inscribed T. Taborski W. Krakowie.

R10 Universal ring sundial: made by Sadtler, Vienna. This eighteenth-century dial has a pin gnomon parallel to the earth's axis and indicates the time by the position of the pin's shadow on a graduated hour circle which is parallel to the equator.

R11 Horizontal and ring sundial: made by M. Kolwein, Vienna. This late seventeenth-century instrument consists of an equatorial ring sundial mounted on the top of the gnomon of an ordinary horizontal sundial which is set for a latitude of 48° 14′.

R12 Universal sundial: this eighteenth-century equatorial dial is arranged to show the time by means of pointers moving over hour and minute circles, and it is inscribed 'Joseph Modestin in Chrudin' (Bohemia).

R13 Brass heliochronometer of Wheatstone type.

R14 Chinese ivory tablet sundial.

R15 Pocket altitude sundial: paper on wood, inscribed 'Hutchinson deli . . .'

R16 Ferguson heliochronometer.

R17 Ivory tablet sundial: by Jasper Milner.

R18 Disc sundial with vane: inscribed Roma, AD 1592.

R19 Tablet sundial: by Hans Troschel.

R20 Octagonal pocket compass sundial with concentric lunar dial.

R21 Oval pocket compass sundial: by Le Sueur, Gisors.

R22 Octagonal brass pocket compass sundial: by Langlois a Paris.

R23 Persian pocket compass sundial.

R24 Universal compass sundial: by And. Vogel.

R25 Ring dial: $1\frac{1}{8}$ in. diameter.

Nocturnals

R26 Early seventeenth-century Italian brass gilt nocturnal.

R27 Wooden nocturnal: stamped 'Mr. Edward Tyzack, 1713'.

R28 Nocturnal and pocket universal sundial: both showing Italian hours. Incomplete.

Perpetual calendars

R29 Perpetual almanack: engraved 'Storr fecit York'.

R30 Silver perpetual calendar: dated 1765.

R31 French iron square sundial and perpetual calendar: dated 1624.

Dipleidoscopes

R32 Dipleidoscope: made by Messrs. E. Dent & Co. This is an instrument for determining the time of apparent solar noon by means of coincidence of two images of the sun. It was originally patented by J. M. Bloxam in 1843.

It consists of an outer piece of glass combined with two interior mirrors to form a hollow prism, the axis of which is fixed parallel to the earth's axis. When light from the sun falls on the instrument, some of it is reflected from the outer surface and gives an image of the sun, while the remainder passing through the outer glass falls on one of the inner mirrors and is reflected on to the other mirror and from there out of the prism to form a second image. If the angle between the outer glass and the direction of the light from the sun be equal to the angle between the two mirrors, these two images will coincide, and the instrument is so fixed that this occurs at solar noon.

R33 Portable dipleidoscope.

R34 Dipleidoscope with clock gearing: this is similar in principle to other dipleidoscopes, but the prism can be turned on its axis to allow for observations of the sun at other times than noon.

Clocks and clock mechanisms

R35 Two bells from Wells Cathedral: these bells were formerly in use with the clock at Wells, and probably date from the fourteenth century.

R36 Large cast steel bell set up in connection with the Wells Cathedral clock: made by Messrs. Vickers in the nineteenth century and is of cast steel instead of the usual bell metal.

R37 Sixteenth-century Augsburg clock (copy): this is an electrotype copy of a clock by Jeremias Metzker of Augsburg, dated 1564. It is remarkable for the variety of information given on its many dials. The clock is fitted with a nineteenth-century French movement which operates only the main 24-hour dial on the front of the clock.

R38 Barometric compensation for the Dent standard clock: photograph of the barometric compensation for the Dent standard clock of 1872 for the Royal Observatory, Greenwich.

Watch mechanisms

R39 Cylinder escapement: made by Messrs. E. Dent & Co. This model was designed to allow an enlarged image to be projected, by reflection, upon a screen. It represents the cylinder or horizontal escapement, invented by George Graham about 1720, which was formerly extensively used for watches.

R40 Lever escapement: made by Dent. This model was designed for use in connection with a projecting lantern and it represents the lever escapement, which in a modified form is now almost universally employed for pocket watches.

R41 Keyless mechanism: made by Dent. This model was designed for projection by reflection on to a screen and it represents a keyless mechanism, introduced about 1850, which has been extensively used in Swiss and other watches.
The essential feature of the mechanism is a pair of ratchet wheels arranged with their teeth on the ends of cylinders, one of which drives the other. For motion in one direction the two sets of teeth interlock and move together, but for motion in the opposite direction the teeth of the driving wheel slide out of engagement. Provision is also made for setting the hands.

Chronometers

R42 Compensation balance-wheel with Mercer's auxiliary compensation.

Japanese clocks

R43 Japanese 'Lantern' clock: this is one of the earlier types of Japanese clock, the movement being made entirely of iron, and probably dates from the late seventeeth century.
It is fitted with two separate escapements, one for use during the day and the other for the night when the Japanese 'hours' were of a different length.

The clock strikes on the usual Japanese system, the sequence of strokes beginning at either noon or midnight being 9, 1, 8, 2, 7, 1, 6, 2, 5, 1, 4, 2. The case of the clock is of iron inlaid with silver and brass and a translation of an inscription on one of the uprights reads – 'Fuwa Gembei, an inhabitant of Nagoya, Bishu (Owari) made this'.

R44 Small Japanese clock in the form of an 'Inro'.

Electric clocks

R45 Bain electric clock: this electrically driven clock is similar in principle to the long-cased Bain electric clock (Catalogue No. 414), but in this modification the coils are fixed and the permanent magnets are mounted on the pendulum.

R46 Electrically driven pendulum: the method of maintaining this pendulum is similar to that employed in the Bain clock. With this pendulum, however, the electrical contacts which control the timing of the impulses are not derived from the pendulum itself, as in the Bain clock, but are made by a 'master' clock of the Bain type. The pendulum is accordingly made to swing in unison with that of this master clock.
This method of synchronization has been used by Messrs. J. Ritchie & Son, and should be compared with that of R. L. Jones, in which the actual drive of the pendulum is by ordinary clock mechanism, the electrical impulses serving for synchronization only.
[See British Patent Specification No. 2,078 of 1872.]
Made by Messrs J. Ritchie & Son, Edinburgh.

R47 Scott's electrically driven clock: this clock, which was patented by Mr H. Scott in 1902, and made by the British Ever-Ready Electrical Co., Ltd, resembles the Hipp clock (Catalogue No. 380) in that an impulse from an electro-magnet is given to the pendulum whenever its arc of swing falls below a predetermined value. With a new battery the pendulum thus receives few but powerful impulses, while with a run-down battery the impulses are weaker but more frequent, the average arc thus being kept fairly constant and independent of the battery voltage.
The impulse is not given at the middle of the swing, and the force necessary to make contact is supplied by the pendulum.
[See British Patent Specification No. 10,271 of 1902 and No. 2,879 of 1903.]

R48 Holden's electrically driven clock: this clock, patented by F. Holden in 1909, is of the type in which the pendulum makes a contact and receives an impulse from an electro-magnet every swing. It is arranged that both contact and impulse shall occur sharply at the middle of the swing, so that variations in these have practically no direct influence on the time-keeping. The clock behaves as an electromotor

running under light load and therefore small variations in this load have very little influence on the arc of swing, which is determined only by the battery voltage.
[See British Patent Specifications No. 14,873 of 1909 and No. 14,126 of 1910.]

R49 Self-winding master-clock and impulse dial: this clock, patented by D. van de Plancke in 1885, and made by La Précision Cie, Brussels, is an ordinary mechanical pendulum clock which makes an electrical contact every half-minute; an electro-magnet is then energised and attracts an armature, the motion of which winds up the driving spring of the clock. At the same time a current impulse is sent out to drive the subsidiary dials.
[See British Patent Specification No. 8,538 of 1885.]

R50 Perret master clock: made by Vve. David Perret Fils, Neuchatel. This type of clock, introduced by Perret about 1900, is a balance-wheel controlled mechanical clock which makes an electrical contact every minute: an electro-magnet then attracts an armature which resets the driving spring. The clock was used as a master clock, sending out impulses every minute to drive subsidiary dials similar to one also in the collection.

R51 Perret impulse dial: this dial is intended for use with a Perret master clock. It was introduced by Perret about 1900 and is of the type in which a ratchet wheel is advanced through the space of one tooth for each impulse.

R52 Campiche impulse dial movement.

Chronographs and chronoscopes

R53 Le Boulengé chronograph: this instrument, introduced in 1867 by P. le Boulengé of Liège, is an improved form of an earlier chronograph invented by him in 1863. It was used for ascertaining the velocity of projectiles and for measuring very short intervals of time.
The instrument consists of a cylindrical column which supports two electro-magnets, from each of which a rod is held in suspension by the circuit.
The upper rod, known as the chronometer, is fitted with a removable zinc tube and is considerably longer than the lower one, which is known as the registrar.
In operation a projectile is fired through two wire screens placed, say, 120 feet apart. The first forms part of an electrical circuit which includes the upper electro-magnet, and the second screen is in another circuit

including the lower electro-magnet. When the first circuit is broken the upper rod is released and falls vertically and, later, when the second circuit is broken the lower rod is similarly released, and falling on the end of a lever releases a circular knife edge which cuts into the zinc tube on the chronometer rod. A special rule is provided from which the velocity of the projectile corresponding with the distance between the knife-cut and a zero line on the tube may be obtained.
For the preliminary adjustments of the instrument arrangements are made whereby both rods are released at the same time.

R54 Chronoscope of Hipp type.

R55 Weight-driven chronoscope with horizontal dial.

Gas-controllers

R56 Early Horstmann solar dial of about 1904 for controlling street lights.

R57 First 'Gunfire' gas-controller for street-lamps giving quick action (patented 1908).

R58 Horstmann single-train controller for street-lights of about 1919, with hand-set dial.

Portraits

R59 Oil painting of George Graham: by T. Hudson.

R60 Oil painting of Thomas Earnshaw.

R61 Oil painting of John Arnold and family.

R62 Mezzotint of Thomas Earnshaw.

R63 Engraving of George Graham: by J. Faber, from painting by T. Hudson.

R64 Print of T. Mudge.

R65 Engraving of Christopher Pinchbeck: by J. Faber, from painting by Isaac Whood.

R66 Engraving of Christopher Pinchbeck: by Humphrey, from original by Cunningham.

R67 Lithograph of W. J. Frodsham.

Index of Donors and Contributors and Photograph Numbers

Catalogue Numbers	*Inventory Numbers*	*Photograph Numbers*	*Donors and Contributors*
1	1923-584	1946	
2	1956-218	297/58	From a drawing by A. R. Thomson, R.A
3	1929-585	5496, 5502	Dr Howard Carter
4	1956-218	296/58	From a drawing by A. R. Thomson, R.A.
5	1926-992	3209	W. M. Hayes, Esq.
6	1923-48	3270, 13 to 18/39, 3266	The Egyptian Government
7	1923-115		The Egyptian Government
8	1960-207		
9	1931-834	9/46	
10	1924-314		Captain M. W. Hilton-Simpson
11	1965-8	325/65, 326/65, 327/65	
12	1965-7	422/65	
13	1964-335		Dr J. Needham
14	1964-335		Dr J. Needham
15	1965-6	328/65	
16	1964-306		
17	1894-131	1157, 3384	
18	1965-4		O. L. Haris, Esq.
19	1926-233	7292	
20	1953-365		
21	1964-303		
22	1964-304		
23	1965-175		By courtesy of the Tower Armouries
24	1954-127		
25	1942-23	55/50	
26	1942-22	56/50	
27	1911-209	5703	
28	1953-414	274/58	
29	1938-641	29/47	F. C. Ihlee, Esq.
30	1937-186		Dr W. L. Hildburgh, F.S.A.
31	1920-360	1590	

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32	1953-304		
33	1953-299		
34	1953-300		
35	1953-302		Abbot Horne Collection
36	1953-303		Abbot Horne Collection
37	1953-301		Abbot Horne Collection
38	1953-312		Abbot Horne Collection
39	1953-403		Abbot Horne Collection
40	1953-308		Abbot Horne Collection
41	1953-307		Abbot Horne Collection
42	1953-404		Abbot Horne Collection
43	1953-405		Abbot Horne Collection
44	1953-406		Abbot Horne Collection
45	1953-407		Abbot Horne Collection
46	1953-311		Abbot Horne Collection
47	1953-309		Abbot Horne Collection
48	1953-310		Abbot Horne Collection
49	1953-313		Abbot Horne Collection
50	1953-314		Abbot Horne Collection
51	1953-315		Abbot Horne Collection
52	1953-408		Abbot Horne Collection
53	1948-135	59/50	
54	1935-11	7712	
55	1958-251	67/59	
56	1920-85	8156	
57	1964-189	504/64	
58	1880-35	196	
59	1880-52		
60	1883-128	19,290	T. H. Court, Esq.
61	1917-96		
62	1952-233	475/53	
63	1880-30	223/66	
64	1880-46		
65	1880-38		
66	1892-17		
67	1937-859	672/37	J. Bentley Bennett, Esq.
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69	1883-124		
70	1883-132	8384	
71	1938-22 and 23	189/38, 190/38	
72	1938-353		W. E. Miller, Esq.
73	1952-442	503/53, 504/53	
74	1955-149	421 to 423/55	
75	1894-10	224/61	
76	1880-29	655/55	
77	1932-553	7243	A. R. T. Woods, Esq.
78	1923-404		Messrs. C. F. Casella & Co, Ltd.
79	1921-816	7242	T. H. Court, Esq.
80	1883-127	216/66	
81	1883-137		
82	1938-342		W. E. Miller, Esq.
83	1953-237		Dr W. L. Hildburgh
84	1938-349		W. E. Miller, Esq.
85	1938-350	217/66	W. E. Miller, Esq.
86	1918-95		T. H. Court, Esq.
87	1887-13		
88	1928-207	559/37, 560/37, 595/37	Dr H. Chatley
89	1957-223		
90	1894-111		
91	1952-235	477/53	
92	1938-374		W. E. Miller, Esq.
93	1938-364	218/66	W. E. Miller, Esq.
94	1883-140	27/47	
95	1880-55		
96	1892-19		
97	1880-54		
98	1938-354	419/38	W. E. Miller, Esq.
99	1914-887		T. H. Court, Esq.
100	1880-53	346/53	
101	1956-230		Mrs B. R. Colin-Jones
102	1883-122	28/47	
103	1888-175		
104	1916-321		T. H. Court, Esq.

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105	1883-121	220/66	
106	1938-107	188/38	
107	1947-280		Mrs A. H. Lloyd
108	1938-351	219/66	
109	1950-10	204 to 208/50	
110	1938-337		
111	1938-358	14/51	W. E. Miller, Esq.
112	1938-356	15/51	W. E. Miller, Esq.
113	1937-832	662/37, 663/37	
114	1938-368		W. E. Miller, Esq.
115	1934-137	8232	T. H. Court, Esq.
116	1894-28	222/66	
117	1894-12	8231A	
118	1894-11	8231	
119	1919-324		T. H. Court, Esq.
120	1938-372		W. E. Miller, Esq.
121	1938-369		W. E. Miller, Esq.
122	1943-20	221/66	
123	1965-1		
124	1897-29	7263	Miss M. B. L. Oliver
125	1922-104		Messrs J. H. Steward, Ltd.
126	1922-156		Messrs. Pilkington & Gibbs, Ltd.
127	1933-408	7262	J. McGregor, Esq.
128	1937-42	32/47	
129	1880-44		
130	1883-120		
131	1938-377		W. E. Miller, Esq.
132	1938-380		W. E. Miller, Esq.
133	1935-629		R. P. Howgrave-Graham, F.S.A.
134	1884-77	193, 194, 166/52	Dean and Chapter of Wells Cathedral
135	1884-76		Messrs. Vickers, Sons & Co
136	1884-81	97	War Office
137	1963-78	457/63	
138	1914-453	3394	Percy Webster
139	1925-704	3070,3071	Rev. C. C. H. James
140	1963-41	634/63, 635/63	
141	1939-320		Metropolitan Police
142	1952-401		Gillett & Johnston, Ltd.

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143	1964-307		
144	1964-308		
145	1964-305		
146	1964-309		
147	1954-184	937/54, 938/54	
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149	1932-441	6023 to 5	W. E. Miller, Esq.
150	1954-579	1/55, 2/55, 3/55	
151	1951-30	377 to 9/51	
152	1951-266		H. Baines, D.Sc.
153	1954-185		
154	1928-1054		W. E. Miller, Esq.
155	1876-70		Royal Institute of 'Studii Superiori', Florence
156	1883-29	96, 290/37	
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158	1956-220		
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160	1927-1981	456/56, 457/56	J. Morrison & Sons
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163	1956-219		
164	1919-260	3336	J. Drummond Robertson
165	1964-225	65/65	C. J. Thorpe, Esq.
166	1928-722	7529	Dr. M. Gepp
167	1934-652	7531, 751/57	J. K. Glenn Sarjeant, Esq. Mrs E. J. Kempson
168	1935-264		
169	1965-5		M. C. Aimer, Esq.
170	1957-94	845/57, 846/57	Victoria and Albert Museum
171	1964-164	146 to 149/65	Victoria and Albert Museum
172	1884-80	536, 535, 3329	G. Empringham, Esq.
173	1884-79	3330, 533, 1234/54, 1235/54	
174	1935-44		Lord Riddell
175	1879-32	3444	R. N. Bloxam, Esq. and Miss D. K. Bloxam
176	1940-15		E. T. Cottingham, Esq.
177	1930-665	8105, 8106, 8108, 8134	
178	1906-56	66/54, 67/54	F. Hope-Jones, Esq.
179	1954-186	935/54, 936/54	

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180	1953-379	939/54	
181	1953-48	808/52, 809/52	
182	1938-429	642/51	W. E. Miller, Esq.
183	1942-57	57/50, 62/50	Mrs V. E. F. Becker
184	1949-232	34 to 36/50	HM King George VI
185	1942-58	58/50	Mrs V. E. F. Becker
186	1964-310		
187	1952-312	695 to 698/50	
188	1954-580	1151-4/54	
189	1954-458	1148 to 1150/54	
190	1964-300		Ronald Lee, Esq.
191	1957-202	45 to 48/58, 120/58, 121/58	Mrs M. L. Gifford
192	1962-263	306/63, 307/63	Miss E. S. Gould
193	1937-889	195/38	P. L. Harrison, Esq.
194	1930-660	7257	P. L. Harrison, Esq.
195	1937-891		P. L. Harrison, Esq.
196	1930-663	7260	P. L. Harrison, Esq.
197	1952-181		D. E. Flinn, Esq.
198	1957-62		P. L. Harrison, Esq.
199	1930-662	7247	P. L. Harrison, Esq.
200	1928-721	7240	
201	1950-11	99/50	S. Peter, Esq.
202	1937-888	191/38, 192/38	P. L. Harrison, Esq.
203	1957-69	63/65	
204	1937-892	196/38	P. L. Harrison, Esq.
205	1965-170		
206	1965-171	526/64, 527/64	
207	1928-1180		
208	1937-289	441/37	W. E. Miller, Esq., F.S.A.
209	1954-578		
210	1954-187	610/54, 611/54	
211	1964-332	826/64, 827/64	
212	1963-303		J. S. Hill, Esq.
213	1916-93		Evan Roberts Collection
214	1916-108		Evan Roberts Collection
215	1916-95		Evan Roberts Collection
216	1916-96	3381	Evan Roberts Collection

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218	1916-121		Evan Roberts Collection
219	1916-120		Evan Roberts Collection
220	1916-116		Evan Roberts Collection
221	1916-109		Evan Roberts Collection
222	1916-124		Evan Roberts Collection
223	1916-113		Evan Roberts Collection
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227	1920-487		Bruno Roberts Collection
228	1920-497		Bruno Roberts Collection
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230	1920-496		Bruno Roberts Collection
231	1953-47		H. Batsford, Esq.
232	1928-1181		Evan Roberts Collection
233	1916-198		Evan Roberts Collection
234	1916-201		Evan Roberts Collection
235	1916-281		Evan Roberts Collection
236	1920-515		Evan Roberts Collection
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238	1928-1188		
239	1920-512		Bruno Roberts Collection
240	1955-163	481/55, 482/55	British Museum
241	1916-207		Evan Roberts Collection
242	1916-204		Evan Roberts Collection
243	1916-205		Evan Roberts Collection
244	1954-151	616/54, 617/54	
245	1916-255		Evan Roberts Collection
246	1916-256		Evan Roberts Collection
247	1955-162	480/55	British Museum
248	1916-259		Evan Roberts Collection
249	1916-260		Evan Roberts Collection
250	1916-261		Evan Roberts Collection
251	1953-54		De Trevars Ltd.
252	1928-1182		
253	1916-146	3378	Evan Roberts Collection
254	1916-159	3378	Evan Roberts Collection

Catalogue Numbers	*Inventory Numbers*	*Photograph Numbers*	*Donors and Contributors*
255	1916-145		Evan Roberts Collection
256	1916-150		Evan Roberts Collection
257	1916-141		Evan Roberts Collection
258	1916-151		Evan Roberts Collection
259	1916-157		Evan Roberts Collection
260	1916-155		Evan Roberts Collection
261	1916-163		Evan Roberts Collection
262	1916-164		Evan Roberts Collection
263	1916-169		Evan Roberts Collection
264	1916-170		Evan Roberts Collection
265	1917-171		Evan Roberts Collection
266	1916-298		Evan Roberts Collection
267	1920-498		Bruno Roberts Collection
268	1920-501		Bruno Roberts Collection
269	1920-505		Bruno Roberts Collection
270	1934-179		G. Pinchard, Esq.
271	1928-1183		
272	1916-262		Evan Roberts Collection
273	1928-1189		
274	1952-58		G. J. Fenn-Wiggin, Esq.
275	1916-182		Evan Roberts Collection
276	1916-179		Evan Roberts Collection
277	1916-180		Evan Roberts Collection
278	1916-183		Evan Roberts Collection
279	1920-550		Bruno Roberts Collection
280	1920-509		Bruno Roberts Collection
281	1920-511		Bruno Roberts Collection
282	1928-1186		
283	1916-190		Evan Roberts Collection
284	1916-276		Evan Roberts Collection
285	1920-519		Bruno Roberts Collection
286	1928-1187		
287	1916-191		Evan Roberts Collection
288	1920-516		Bruno Roberts Collection
289	1928-1184	8676	
290	1916-195		Evan Roberts Collection
291	1916-287		Evan Roberts Collection
292	1901-76	187/63	Sir Edwin Durning-Lawrence, Bart.

Catalogue Numbers	Inventory Numbers	Photograph Numbers	Donors and Contributors
293	1928-1185		
294	1916-196		Evan Roberts Collection
295	1920-522		Evan Roberts Collection
296	1920-554		Evan Roberts Collection
297	1951-246	425/51	J. A. Cousins, Esq.
298	1952-1	130/52 to 132/52	HM Queen Mary
299	1953-53		De Trevars, Ltd.
300	1920-557		Bruno Roberts Collection
301	1953-23		G. H. Baillie, Esq.
302	1953-380	696/54, 697/54	Victoria & Albert Museum
303	1952-59		G. J. Fenn-Wiggin, Esq.
304	1936-132		Major E. O. Henrici
305	1920-490		Bruno Roberts Collection
306	1920-543		Bruno Roberts Collection
307	1916-217		Bruno Roberts Collection
308	1935-495	188/63	Gregory Tovey, Esq.
309	1930-152		H. W. Ravenshaw, Esq.
310	1930-153		H. W. Ravenshaw, Esq.
311	1930-154		H. W. Ravenshaw, Esq.
312	1930-155		H. W. Ravenshaw, Esq.
313	1930-156		H. W. Ravenshaw, Esq.
314	1930-157		H. W. Ravenshaw, Esq.
315	1930-158		H. W. Ravenshaw, Esq.
316	1930-162		H. W. Ravenshaw, Esq.
317	1916-149		Evan Roberts Collection
318	1916-147		Evan Roberts Collection
319	1920-507		Bruno Roberts Collection
320	1915-408	3377	Edwin Earnshaw, Esq.
321	1920-544		Bruno Roberts Collection
322	1916-184		Evan Roberts Collection
323	1916-187	3377	Evan Roberts Collection
324	1916-188	189/63	Evan Roberts Collection
325	1916-186		Evan Roberts Collection
326	1916-264		Evan Roberts Collection
327	1950-28	186/63	Miss G. M. Hodges
328	1965-9	108/65, 109/65	Warren Pollock, Esq.
329	1938-318	314/47, 315/47	Cyril G. B. Judd, Esq.
330	1944-9	302/55	Major E. R. Rivers

Catalogue Numbers	Inventory Numbers	Photograph Numbers	Donors and Contributors
331	1952-225	70/53	R. McV. Weston, Esq.
332	1954-189	614/54, 615/54	
333	1916-106		Evan Roberts Collection
334	1916-107		Evan Roberts Collection
335	1916-214		Evan Roberts Collection
336	1916-172		Evan Roberts Collection
337	1916-213		Evan Roberts Collection
338	1916-218		Evan Roberts Collection
339	1963-165	473/63, 86/64	
340	1954-63		Antiquarian Horological Society
341	1938-321		Cyril G. B. Judd, Esq.
342	1954-188	612/54, 613/54	
343	1955-164	483/55	British Museum
344	1916-208		Evan Roberts Collection
345	1916-209		Evan Roberts Collection
346	1916-210		Evan Roberts Collection
347	1920-541		Bruno Roberts Collection
348	1920-535		Bruno Roberts Collection
349	1920-538		Bruno Roberts Collection
350	1920-558		Bruno Roberts Collection
351	1920-536		Bruno Roberts Collection
352	1920-539		Bruno Roberts Collection
353	1936-133		G. R. Kirby, Esq.
354	1938-320		Cyril G. B. Judd, Esq.
355	1963-164	425/63, 426/63	J. S. Hill, Esq.
356	1958-263	191/63	
357	1953-55		De Trevars, Ltd.
358	1953-56		De Trevars, Ltd.
359	1964-331	828/64, 829/64	
360	1916-223		Evan Roberts Collection
361	1916-239		Evan Roberts Collection
362	1916-234		Evan Roberts Collection
363	1916-236		Evan Roberts Collection
364	1916-237		Evan Roberts Collection
365	1916-238		Evan Roberts Collection
366	1916-247		Evan Roberts Collection
367	1916-242		Evan Roberts Collection
368	1916-248	597/50, 598/50	Evan Roberts Collection

Catalogue Numbers	Inventory Numbers	Photograph Numbers	Donors and Contributors
369	1916-263		Evan Roberts Collection
370	1916-241		Evan Roberts Collection
371	1920-534	780/55	Bruno Roberts Collection
372	1920-549		Bruno Roberts Collection
373	1920-530		Bruno Roberts Collection
374	1920-533		Bruno Roberts Collection
375	1920-531		Bruno Roberts Collection
376	1920-527		Bruno Roberts Collection
377	1948-88	778/55	G. J. Fenn-Wiggin, Esq.
378	1938-322		Cyril G. B. Judd, Esq.
379	1938-317	779/55	Cyril G. B. Judd, Esq.
380	1936-375 to 378		
381	1903-163		
382	1879-31	7246	C. Frodsham, Esq.
383	1917-112		Samuel Edgcumbe, Esq.
384	1929-937		Lt J. F. Godwin, R.E.
385	1906-53		
386	1906-54	7245	
387	1920-568		Bruno Roberts Collection
388	1918-187		Commodore Sir D. E. Brownrigg
389	1925-193		
390	1925-193		
391	1931-716		Messrs Thomas Mercer
392	1883-67		
393	1929-69 to 76	7241	Messrs Thomas Mercer
394	1884-75	7251	E. T. Loseby, Esq.
395	1926-251	7274	V. Kullberg, Esq.
396	1925-194	7259	Paul Ditisheim, Esq.
397	1964-301		
398	1909-199		
399	1935-8		Messrs J. H. Willis & Co
400	1964-312		
401	1883-54		
402	1883-64		
403	1925-51	159/48, 159A/48	J. M. Kleyser, Esq.
404	1958-190		
405	1928-300	160/48	T. A. Winter, Esq.

Catalogue Numbers	Inventory Numbers	Photograph Numbers	Donors and Contributors
406	1951-25	376/51	A. W. Whiting, Esq.
407	1926-165	162/48	
408	1938-554 and 555		
409	1949-114		Horstmann Clifford Magnetics, Ltd.
410	1951-59		Rotherham & Sons, Ltd.
411	1959-64 and 166		Horstmann Clifford Magnetics, Ltd.
412	1952-341 to 348	461 to 469/53	Mr & Mrs Charles Hobson
413	1956-164		Smith's Clocks & Watches, Ltd.
414	1962-131	400/63 to 402/63	
415	1949-303	82/55	King's College, London
416	1950-216	159/51	G. W. Grabham, Esq.
417	1949-181	90/55	
418	1913-580		
419	1913-568	83-55	Prof. Charles Fery
420	1922-675	84/55, 85/55	The British Horo-Electric, Ltd.
421	1913-567	7244, 88/55	Prof. Silvanus P. Thompson, F.R.S.
422	1913-570	184/49, 213/49	Gustave Kutnow, Esq.
423	1964-111		S. Smith & Sons (England), Ltd.
424	1947-114	86/55	Hillyard T. Stott, Esq.
425	1912-234	87/55	F. Hope-Jones, Esq.
426	1947-99	60/50	The Telephone Manufacturing Co. Ltd.
427	1946-193	133/49	Captain E. E. Craig
428	1959-84		E. G. Parriss, Esq.
429	1912-231	89/55	F. Hope-Jones, Esq.
430	1935-127		F. Hope-Jones, Esq.
431	1935-127		F. Hope-Jones, Esq.
432	1939-310	211/49, 212/49	Mrs K. I. Bartrum
433	1948-340		Mrs K. I. Bartrum
434	1935-126 and 1964-13	7626, 7627	The Synchronome Co. Ltd.
435	1935-127	91/55	The Synchronome Co. Ltd.
436	1912-241		Capt. F. E. Dyke Acland
437	1912-239		The Aron Electricity Meter Co. Ltd.
438	1912-236		F. Hope-Jones, Esq.
439	1912-228	7250	F. Hope-Jones, Esq.
440	1912-238	92/55	Sir W. C. Leng & Co. Ltd.
441	1912-235	7256	F. Hope-Jones, Esq.

Catalogue Numbers	Inventory Numbers	Photograph Numbers	Donors and Contributors
442	1912-229		F. Hope-Jones, Esq.
443	1912-230		F. Hope-Jones, Esq.
444	1951-288		Messrs Gent & Co. Ltd.
445	1913-195	8233, 96/55	Messrs Gent & Co. Ltd.
446	1938-333		The Telephone Manufacturing Co. Ltd.
447	1938-334	94/55	The Telephone Manufacturing Co. Ltd.
448	1960-1	378/60	Magneta (B.V.C.) Ltd.
449	1960-2		Magneta (B.V.C.) Ltd.
450	1965-177		International Time Recording Co. Ltd.
451	1965-179		International Time Recording Co. Ltd.
452	1959-50		International Time Recording Co. Ltd.
453	1909-474	7275	The Imperial Institute
454	1913-581	95/55	The Metropolitan District Railway Co.
455	1927-987		The Warren Telechron Co. U.S.A.
456	1931-516	7699	Everett Edgcumbe & Co. Ltd.
457	1931-517		Everett Edgcumbe & Co. Ltd.
458	1931-659	590/59	Smiths English Clocks, Ltd.
459	1934-63		Ferranti Ltd.
460	1953-265		Venner Ltd.
461	1957-155		C. D. Harwood, Esq
462	1932-618		
463	1958-248		The Hamilton Watch Co. U.S.A.
464	1963-304		Ebauches S. A., Neuchâtel
465	1963-306		Garrard & Co. Ltd.
466	1947-310 and 311	736/64, 737/64	Post Office Research Station
467	1954-457		National College of Horology
468	1947-311, 1958-218 and 219		Post Office Research Station
469	1962-59		National Physical Laboratory
470			
471	1961-21		
472			
473			
474	1889-38	8228	
475	1959-115		Venner Electronics Ltd.
476	1876-377	98	Rev. F. Bashforth
477	1933-169		

Catalogue Numbers	Inventory Numbers	Photograph Numbers	Donors and Contributors
478	1964-250		Television Audience Measurement Ltd
479	1965-		Television Audience Measurement Ltd
480	1957-45 and 1915-95		
481	1934-664	7445, 7446	International Time Recording Co. Ltd.
482	1934-665	7447	International Time Recording Co. Ltd.
483	1965-181		International Time Recording Co. Ltd.
484	1965-182		International Time Recording Co. Ltd.
485	1961-69		Magneta (B.V.C.) Ltd.
486	1959-52		International Time Recording Co. Ltd.
487	1951-217	1155/54	
488	1920-564		Bruno Roberts and Mrs J. Williamson
489	1959-291 and 292		Venner Ltd.
490	1883-53		
491	1883-95		
492	1937-290		W. E. Miller, Esq.
493	1938-31		H. G. Easterbrook, Esq.
494	1938-133		The Horstmann Gear Co. Ltd.
495	1938-462		B.F.C.A.L.C. Co. Ltd.*
496	1938-463		B.F.C.A.L.C. Co. Ltd.*
497	1938-137 and 138		The Horstmann Gear Co. Ltd.
498	1938-134		The Horstmann Gear Co. Ltd.
499	1932-474		Venner Time Switches Ltd.
500	1965-234		
501	1953-336 and 1965-235		Venner Ltd.
502	1953-337		Venner Ltd.
503	1952-296		Industriaktiebolaget Reflex, Sweden
504	1965-180		International Time Recording Co. Ltd.
505	1883-74		
506	1924-295		R. N. Shaw, Esq.
507	1939-259 and 1946-237		Messrs De Trevars, Ltd.
508	1884-217	1103/52	W. H. Barton, Esq.
509	1962-374		R. R. Earnshaw, Esq.
R1	1942-21		
R2	1952-184	69/56	F. H. Nash, Esq
R3	1953-448		Abbot Horne Collection

**The British, Foreign and Colonial Automatic Light Controlling Co. Ltd*

Catalogue Numbers	Inventory Numbers	Photograph Numbers	Donors and Contributors
R4	1876-322		The Archaeological Museum, Madrid
R5	1944-43		
R6	1946-171		Dr W. L. Hildburgh
R7	1894-107		
R8	1916-8		T. H. Court, Esq.
R9	1894-8	208	
R10	1918-97		T. H. Court, Esq.
R11	1880-40		
R12	1880-45		
R13	1949-301		King's College London
R14	1953-316		Abbot Horne Collection
R15	1951-272		
R16	1951-302		
R17	1938-371	191/47	Miller Collection
R18	1938-348		Miller Collection
R19	1938-361		Miller Collection
R20	1938-367		Miller Collection
R21	1938-341		Miller Collection
R22	1938-343		Miller Collection
R23	1938-373		Miller Collection
R24	1938-359		Miller Collection
R25	1938-363		Miller Collection
R26	1880-42		
R27	1908-165		E. Ball Knobell, Esq.
R28	1952-234		
R29	1938-753		T. H. Court, Esq.
R30	1943-21		
R31	1944-43		
R32	1900-178		W. Tucker Radford, M.B.
R33	1876-1021		E. Dent & Co.
R34	1917-98		T. H. Court, Esq.
R35	1887-73		
R36	1884-76		Messrs Vickers, Sons & Co.
R37	1949-207		C. L. Goggs, Esq.
R38	1876-76		E. Dent & Co.
R39	1883-65		E. Dent & Co.
R40	1883-66		
R41	1883-68		

Catalogue Numbers	Inventory Numbers	Photograph Numbers	Donors and Contributors
R42	1936-55		G. R. Kirby, Esq.
R43	1893-171	3337	
R44	1951-568		R. L. Hine, Esq.
R45	1913-580		
R46	1913-562		Messrs J. Ritchie & Son
R47	1912-240		Herbert Scott, Esq.
R48	1949-25		W. R. T. Foreman, Esq.
R49	1912-224 and 225		F. Hope-Jones, Esq.
R50	1912-250		Vve. David Perret Fils
R51	1912-400		Messrs Dykes Bros.
R52	1912-232		F. Hope-Jones, Esq.
R53	1887-27	99	
R54	1949-302		King's College, London
R55	1949-304		King's College, London
R56	1938-139		Horstmann Gear Co. Ltd.
R57	1938-464		B.F.C.A.L.C. Co. Ltd.*
R58	1938-135		Horstmann Gear Co. Ltd.
R59	1868-249	1102/52	C. Frodsham, Esq.
R60	1903-178	4997	Woodcroft Bequest
R61	1868-248	1897	C. Frodsham, Esq.
R62	1903-162		Woodcroft Bequest
R63	1884-218		
R64	1884-225		C. Frodsham, Esq.
R65	1884-219		
R66	1884-220		
R67	1903-161		Woodcroft Bequest

**The British, Foreign and Colonial Automatic Light Controlling Co Ltd.*

List of Makers of Watches included in this catalogue

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